Technical Report 2012-5

IDAHO COOPERATIVE FISH AND WILDLIFE RESEARCH UNIT

EVALUATION OF DUAL FREQUENCY IDENTIFICATION SONAR (DIDSON) FOR MONITORING PACIFIC LAMPREY PASSAGE BEHAVIOR AT FISHWAYS OF BONNEVILLE DAM, 2011

by

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Executive Summary

The relationship between lamprey swimming behavior and passage success in fishways remains unclear, though previous telemetry studies have indicated poor passage at several locations including fishway entrances and transition pools. In the summer of 2011, we completed a Dual-Frequency Identification Sonar (DIDSON) pilot study at Bonneville Dam to evaluate potential applications of this technology for passively observing Pacific lamprey (*Entosphenus tridentatus*) behavior and passage at fine scales (1-5 m). A secondary objective was to determine whether DIDSON monitoring could provide quantitative estimates for common passage metrics (e.g., entrance efficency).

Two DIDSON cameras were deployed from 6 June to 2 September among six existing locations at Bonneville Dam (Washington-shore junction pool, Powerhouse 2 north upstream and downstream entrances, Powerhouse 2 south upstream and downstream entrances, and Cascades Island fishway entrance [excluded from analysis because we found the available deployment location was unsuitable]). Data were collected in high frequency mode at each location for periods of 24 to 72 hours. DIDSON images were collected in landscape mode—with the long axis of the sample volume parallel to the ground to obtain information on upstream and downstream movements and to assess horizontal distribution. Images were also collected in portrait mode to identify lamprey depth distributions. We also summarized the presence or absence of white sturgeon (*Acipenser transmontanus*), a lamprey predator.

We collected 1,413 h of DIDSON imagery and a total of 228 h of imagery was viewed (16% of total collected) using a randomized sub-sampling approach. Overall, 123 h were landscape files (54% of the viewed sample) and 105 h were portrait files (46%). Two-thirds of the sub-sample was from night-time hours, which were preferentially sub-sampled given the higher nocturnal activity of the species. We developed a set of morphological and behavioral criteria that were used to identify acoustic targets as adult lamprey with three confidence levels.

We found that we were generally able to distinguish adult lamprey from other species because of their morphology and unique swimming behavior. In a quality control evaluation, six trained technicians independently watched 11.5 h of DIDSON landscape and portrait files and scored lamprey events. There was considerable variability among viewers and between deployment sites, particularly in portrait mode and for events scored with 'low' confidence. Among-viewer agreement increased with the confidence level for the target, which was often a function of how long lamprey were visible. Scoring differences among viewers indicate that adequate DIDSON training and careful post-processing quality control evaluations are needed in future DIDSON studies.

This pilot study demonstrated that DIDSON technology can provide useful assessments of behavior and distribution of adult lamprey movements near fishway entrances and inside fishways within the sampling range (6-7 m) of the instrument. The DIDSON was particularly valuable for assessing movements and behavior at night and in turbid conditions which would have limited use of optical cameras to ranges of less than one meter. The DIDSON allowed us to characterize net lamprey movements and their heading (i.e., orientation in landscape mode) as they passed through the acoustic beams. We observed many lamprey swimming throughout the

sampled portion of the water column, including in mid-channel locations at fishway entrances. In situ swimming depths within our sample volume did not indicate a consistent depth preference during the day or night. However, it was not possible to sample the bottom strata near fishway floors at most sites because I-beams available for DIDSON mounting did not reach the bottom. We observed very few lampreys that attached to substrate or walls at the sampled depths but we did observe entrance events by adults. When white sturgeon were present we generally observed fewer lamprey events and lamprey were more likely to move downstream. These results suggest a reduction in activity or avoidance by adult Pacific lamprey in the presence of sturgeon.

Direct comparison of DIDSON-based metrics to active telemetry metrics such as radio-telemetry (RT) was challenging in part because no lampreys were radio-tagged in 2012. Gross-scale behaviors observed with the DIDSON, such as diel activity and fishway entrance and exit behaviors were similar to radiotelemetry-based results at many of the sampling locations. Comparison of entrance efficiency metrics revealed agreement at some sites but not others. Some of the differences we observed between technologies was likely an artifact of sampling only a small portion of the water column at each site with the DIDSON (i.e., sub-sampling effects), non-random sampling through time (i.e., date effects), and among-site differences in DIDSON deployment depth and orientation. Most importantly, the DIDSON sampled only a slice of the fishway volume (< 50%) at any location, and provided no individual fish data or fate information. Lack of directly comparable results highlighted the need to further develop and test DIDSON and the need to conduct simultaneous monitoring programs that employ multiple methods.

Overall, we found that the DIDSON was an effective monitoring tool for detailed observation of adult lamprey behavior at the fine- to meso-scale (i.e., < 10 m). DIDSON can therefore be effectively used to evaluate research questions about lamprey behavior near and inside fishways when used in study designs that carefully consider the optimum placement of the camera, the limited observation range and volume of the instrument, and the inability to track individual fish. Qualitative findings indicate that DIDSON can be used to: (1) develop repeatable protocols for identification of acoustic targets such as adult lamprey, (2) infer lamprey swimming direction, including fishway entrance and exit behavior, (3) quantify differences in day- versus night-time activity, (4) quantify lamprey depth distributions and lateral distributions within the sampled volume, and (5) identify white sturgeon-lamprey interactions. These data provide important and complementary results to PIT, radio and acoustic telemetry studies.

Introduction

Runs of Pacific lamprey (*Entosphenus tridentatus*) in the Columbia River Basin have declined over the past several decades. Fishways at many dams in the Pacific Northwest were designed to facilitate passage by adult salmonids with high burst swim speeds. As a result, fishways have been identified as contributors to the lower passage success of adult lampreys (<50%, Moser et al. 2002; Johnson et al. 2011), particularly compared to adult salmonids (i.e., often >90%, Caudill et al. 2007). Past radiotelemetry studies indicated that adult lamprey have difficulty entering fishways, passing transition pool areas and areas of the fishway with diffuser gratings, near count windows, and the serpentine weir sections of fish ladders (Moser et al. 2002; Keefer et al. 2011). Radio-telemetry provides spatial resolution of fish position within 5-10 m of underwater antennas and past telemetry studies have been able to identify the general areas of poor passage. However, these studies were unable to identify the specific structures or locations where adult lamprey failed to pass. Consequently there is a need for finer-scale assessments of specific lamprey behaviors and fishway features associated with poor or failed passage in support of the design of future fishway improvements.

The availability of sonar has provided efficient, effective, and passive monitoring of adult and juvenile runs of fish (primarily salmonids) during migration (Ransom 1991; Thorne and Johnson 1993; Ransom and Steig 1994; Steig 1994; Ransom et al. 1996; Steig and Iverson 1998). Generally, these studies monitored and enumerated fish passing weirs in large unregulated systems or at sites that were too turbid for visual counts. More recently, sonars have been used to monitor fish behavior and movement upstream and downstream from hydropower dams, enumerate salmonid redds, help develop bioenergetic models, and study diel spawning patterns (Tiffan et al. 2004, 2005; Boswell et al. 2008; Mueller et al. 2010).

Sonar provides a non-invasive 'mesoscale' sampling tool in the monitoring toolbox. The high resolution and multi-beam sonar DIDSON occupies a niche between short-range optical cameras and low-resolution, long-range radio- and acoustic telemetry systems. The visual range of optical and infrared video is 0.5-2 m (microscale) depending on turbidity, whereas the spatial resolution of radiotelemetry and acoustic telemetry is generally > 10 m (macroscale). DIDSON also has advantages over traditional, single and split-beam echo sounders because it shows the size and general shape of the fish, providing behavioral and species information.

The primary objective of this pilot study was to assess the feasibility of using DIDSON imaging as a sampling tool to monitor adult Pacific lamprey in dam fishways. In 2011, we evaluated the ability of DIDSON technology at Bonneville Dam to consistently identify adult lamprey, characterize adult lamprey behavior at fishway entrances, inside fishways at known passage obstacles, in the presence of predatory fish (white sturgeon, *Acipenser transmontanus*), and to quantify passage metrics. At Bonneville Dam specifically, there is a need for passive micro- to meso-scale lamprey behavioral assessments, particularly in response to specific operational and structural fishway modifications (e.g., reduced night-time fishway entrance velocity or the Cascades Island fishway entrance re-design) and in relation to predatory white sturgeon inside fishways. Our specific pilot study objectives included: (1) measuring lamprey behavioral responses to fishway features, (2) quantifying depth distributions at fishway at fishway entrances, (3) characterizing interactions with predators, (4) quantifying fishway entrance and exit rates, (5) assessing the effectiveness of using DIDSON to estimate lamprey passage efficiency metrics. Prior to addressing these biological objectives, we first developed methodologies for reviewing and scoring imagery, including quantitatively assessing among-viewer consistency in scoring lamprey behaviors from DIDSON imagery.

Methods

The DIDSON camera was developed by the University of Washington’s Applied Physics Laboratory (Belcher et al. 1999, 2001; Tiffan et al. 2004) and uses a high resolution acoustic lens to produce images of the underwater environment. It is conventionally used where underwater cameras would be limited by low light levels and/or high turbidity. In past studies, the images within 8-10 m of the sonar camera were of high enough resolution to identify fish orientation, heading, and direction of movement (Moursund et al. 2003; Holmes et al. 2006). Johnson et al. (2011) recently demonstrated DIDSON effectiveness for assessing lamprey behavior at fish ladder entrances. The multibeam nature of the DIDSON makes it robust in the acoustically noisy environments commonly encountered at hydropower facilities and the operating frequencies are beyond the range known to affect fish behavior (Fay and Simmonds 1999).

We deployed two DIDSON 300 M sonars during the field season (Sound Metrics Corp., Bothel, WA). Each DIDSON consisted of a transducer array, acoustic lens and electronics contained in a waterproof housing. The DIDSON transmitted data to a topside control box using an underwater telemetry cable. A laptop was used to control the DIDSON settings and displayed images in real-time. One of the DIDSON cameras was mounted to a 2-axis X2 Rotator (Sound Metrics Corps, Bothel, WA) that allowed the operator to remotely pan and tilt the camera using laptop computer controls. The other camera was mounted to a manual 2-axis aluminum mount. A 1 TB removable storage drive (Western Digital) was used to transfer data to a larger 10 TB network drive (Netgear Ready NAS) for continuous storage. The DIDSON has low- (1.0 MHz) and high-frequency (1.8 MHz) modes. In the high frequency mode, each beam is 0.3° in the horizontal and 14° in elevation. There are 96 beams spanning 29° in the horizontal direction for a total field of view of 29° (horizontal) x 14° (vertical). A spreader lens was used to “double” the sample volume for a total field of view of 29° (horizontal) x 28° (vertical). The high frequency mode was the most useful for our deployments as it provided higher resolution images that allowed us to distinguish shape, movement, size, and orientation of adult Pacific lamprey.

High resolution files were saved at 10-min increments to facilitate data review with the sampling location, date, and frequency written directly into the data files. The data were set to record at 10 frames/s. This frame rate allowed us to differentiate the unique shape and swimming motion of lamprey from other targets. Where possible, the sonar was typically positioned to sample perpendicular to the lateral plane (side) of the fish (i.e., the sample volume spread across the water column in a near-horizontal orientation instead of vertically through the water column). The sonar was aimed across fishway channels perpendicular to the flow. This configuration maximized the potential for insonifying fish perpendicularly along the longitudinal plane (in a side-aspect) as they swam through the acoustic field. The DIDSON depth varied somewhat with each deployment. We found it useful to have some structure in the field of view for spatial reference when determining the fish’s orientation within the fishway and direction of swimming.

Deployments were conducted from 9 June – 2 September at established monitoring sites near fishway entrances and inside fishways at Bonneville Dam. Sampling locations at the Powerhouse 2 (PH2) and Cascades Island (CI) fishways are shown in Figure 1 (See Appendix B for photos). Study sites included five locations at PH2 and one site at Cascades Island (CI). PH2 study sites included the north downstream entrance (NDE) where entrance modification will begin in 2012-2013, the south downstream and south upstream entrances (SDE, SUE) where high fishway exit rates by lamprey are known to occur (Clabough et al. 2011), and the PH2 junction pool (JP) which is an area of concern because of high lamprey turn-around rates, extensive diffuser gratings, complex hydraulics, and potential predation risk by white sturgeon. The sixth study site was located at the CI fishway just upstream from the fishway entrance and bollards that were installed in 2010-2011 to reduce water velocity along the fishway floor. Deployments at all sites were limited to existing vertical I-beams used in a previous USACE study to deploy acoustic devices to deter marine mammals from entering fishways. These sites allowed for surveillance of approximately upper 15% of the fishway channel in the vertical plane with excellent coverage spanning the channel width except at the wider Cascades Island site. Data collection parameters included a sample window start < 2 m (usually 1.12m) and a window length < 6 m (usually 4.5 or 5 m) (See Appendix A).

The DIDSON sonar and rotator were mounted to an aluminum I-beam trolley and deployed and retrieved using a Thern Series 5122 portable davit crane with a 500 lb capacity. A second DIDSON without a rotator was used concurrently that mounted to an adjustable aluminum bracket that allowed for flexibility (pan and tilt) in aiming the camera. The laptop computer, DIDSON topside control box, and battery backup were housed in a water resistant wooden box located near the I-beams on the roadway deck. This system was powered using a 120-V source located near the sampling sites.

Sonar orientation

Most of the monitoring in 2011 was conducted with the DIDSON in ‘landscape mode’ with the camera oriented so that the pan axis of the rotator moved the camera along the horizon and the 29° component of the sample volume spread laterally (Figure 2). When oriented perpendicular to the flow field (as in Figure 2), the landscape orientation provided information on the upstream and downstream movements of fish and distance of fish from the camera (range). The landscape images appear as a “top view” or plan view of the sample area.

To monitor a larger portion of the vertical plane, the pan axis of the DIDSON was rotated 90° into ‘portrait mode’ by mounting the rotator directly to the I-beam. Portrait mode provided information on the depth of fish within the sample volume with a “side-view” or elevation view of the sample area. In a pilot test to determine the feasibility of collecting three-dimensional information on adult lamprey movement, both cameras were mounted on a trolley in the horizontal (landscape) and vertical (portrait) orientation (stacked cameras) and simultaneously deployed (Appendix B Figure 6). At the fishway entrance sites, the camera was generally positioned above the height of the adjustable entrance gate with a tilt (<10°) downward from horizontal but this varied throughout the sample season in response to tailwater elevation. This orientation placed the bottom edge of the beams close to the top of the adjustable gate.

Multiple angle deployments

We evaluated whether programming the rotator to tilt the camera periodically could be used to sample a greater portion of the water column by collecting multiple sample volumes through time. We tested an automated tilting feature of the DIDSON at the JP site during two 6 h sampling periods. The DIDSON, in landscape mode, was programmed at 20-min increments to move between three different horizontal angles (-26, 1, +30). The technique was used to cover a much broader vertical sampling area than was possible without multiple cameras and was tested as a possible alternative to portrait mode for sampling in the vertical plane. As in other deployments, we found it useful to have some structure in the field of view for spatial reference to aid in determining the fish's orientation within the fishway and direction of swimming.

During the data scoring for the tilting camera deployment we created an index of white sturgeon abundance at the three deployment angles. The index was a relative measure only, and was calculated by counting the number of white sturgeon visible in approximately 50 frames from each file at each deployment. Frames were selected using frame number, with every multiple of 250 frames viewed. This was the equivalent of viewing a frame at approximately 30 sec intervals.

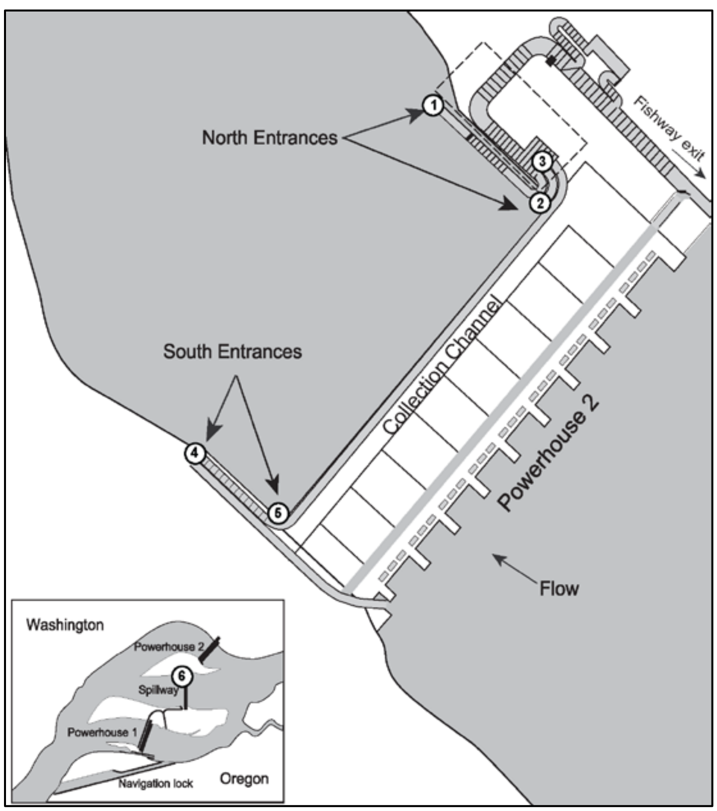

Figure 1. Locations of DIDSON camera deployments in 2011 at Bonneville Dam: 1) North downstream entrance (NDE), 2) North upstream entrance (NUE), 3) Junction Pool (JP), 4) South downstream entrance (SDE), 5) South upstream entrance (SUE), and 6) Cascades Island entrance (CI).

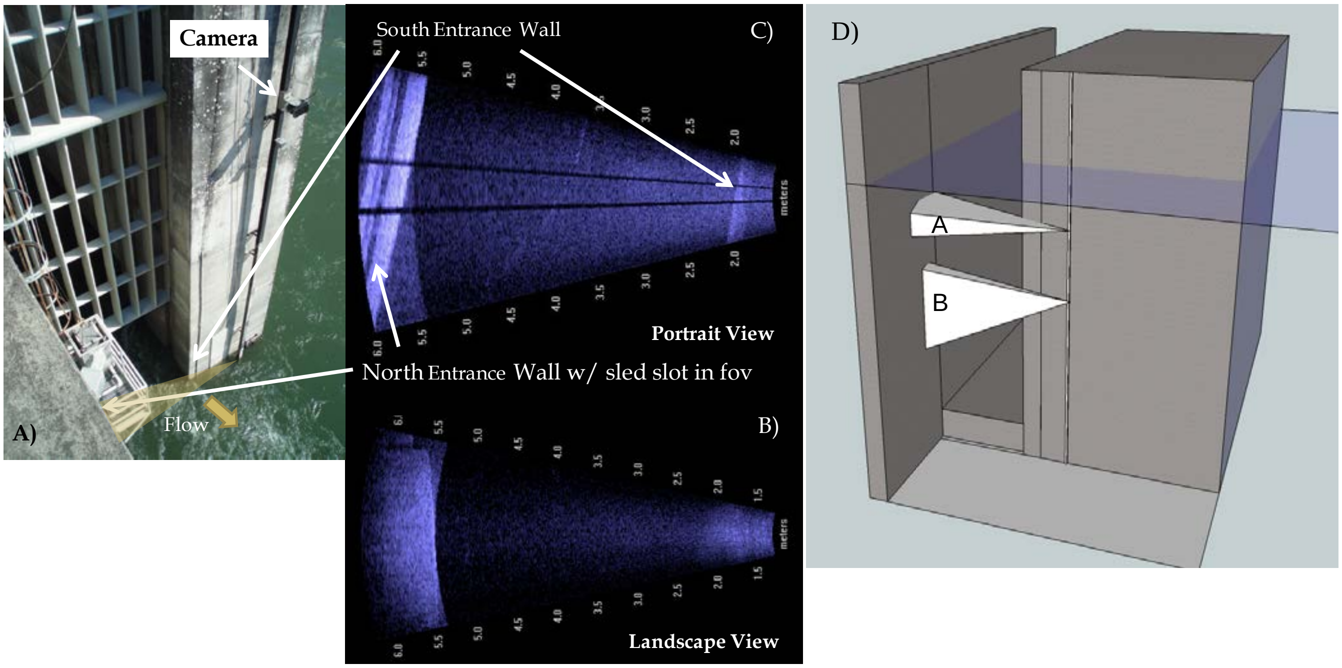

Figure 2. Figure depicting DIDSON camera orientation deployments: A) DIDSON camera in portrait orientation as it was being lowered on an I-beam at NDE. The orange triangle depicts the approximate orientation of the sample volume once deployed. B) DIDSON image just downstream of the entrance in landscape view. C) DIDSON image just downstream of the entrance in portrait view. D) Schematic illustration of the sample volumes with respect to the fishway entrance in landscape (A) and portrait orientations (B).

Data review and analysis

Raw data files were processed by six fisheries personnel using DIDSON v5.25.25 software. Several criteria were developed to identify adult lamprey, including:

1. anguilliform swimming motion (Breder 1926), as opposed to subcarangiform motion of salmonids (*Oncorhynchus* spp.) and American shad (*Alosa sapidissima*). In particular the wavelength relative to the body length of swimming lamprey was shorter in lamprey than in salmonids or shad. A full waveform was often visible in lamprey but only one half a waveform was visible in salmonids and shad. In other words, lamprey frequently appeared s-shaped, while salmonids and shad appeared c-shaped.
2. target shape, including length:width ratio and lack of protruding fins
3. target size of ~50-80 cm
4. other characteristic lamprey behaviors such as attachment to surfaces

To standardize lamprey identification and scoring of DIDSON files, all viewers independently watched and scored lamprey detection events from a common set of training files. All viewers then collectively reviewed the common files and event scoring with an experienced

DIDSON technician. This training exercise produced the lamprey identification criteria listed above. Because there was considerable among-viewer variability in the initial scoring and variability in the duration and quality of individual target images, we used confidence levels (low, medium, high) to classify each lamprey event. 'High' confidence was assigned to events that met most or all of the lamprey identification criteria. 'Medium' confidence was assigned to events that had one or two of the characteristics, and 'low' confidence was assigned to events that were potentially lamprey but had few conclusive characteristics. These scores were necessarily qualitative given considerable variability in the time lamprey were in the field of view, the number of other fishes present, and image differences related to the deployment mode (landscape, portrait) and orientation of the lamprey to the camera.

Once a target was identified, we used tools in reviewing software to measure the image range (distance from camera) and image angle (location in the horizontal plane in landscape mode or in the vertical plane in portrait mode) with respect to the camera. Range and angle were recorded for the first and last image of each individual lamprey target. Viewers also recorded lamprey heading (i.e., facing into the current or facing downstream), whether the lamprey attached to substrate, attachment location, whether white sturgeon were present, and details of the DIDSON file (filename, site, date, review rate [frames/sec], review date). Review rates ranged from 10-20 frames/sec. Data for each event were entered into spreadsheets and events recorded by all viewers were compiled into a master database. Display threshold and intensity settings were manually adjusted by each reviewer to optimize the contrast of the targets.

Because far more data files were collected than could be processed (Table 1), we used random subsampling to select files for review. Initially, all sites and deployments were equally represented. However, image quality was poor at the Cascades Island site, which was deployed using longer frame lengths, and files from this location were eventually excluded from all subsequent analyses. Similarly, some files at the JP site were excluded because of insufficient resolution at the long field of view (range ~12 m) and a batch of portrait files at the SDE site were excluded due to a deployment error. Despite these issues, the vast majority of the collected data were of good quality. The *a priori* subsampling scheme slightly favored night-time files over day-time files (2:1 ratio) because of the primarily nocturnal activity of lamprey at fishways and favored landscape mode files over portrait mode files (1.5:1 ratio) because initial review of images indicated lampreys could be identified with greater confidence in landscape mode. The selected subsample was randomly distributed among viewers as much as possible. Viewer availability and minor shifts in viewing priority based on preliminary results precluded strictly random assignment.

Among-viewer comparison: Quality control evaluation

In addition to the common set of training files, we compared the consistency of scoring among viewers using a set of 69 10-min files (11.5 h) that were watched by all six viewers. These files were randomly selected from the subsample described above and were distributed throughout the viewing period. Five of six viewers did not know which DIDSON files were multi-viewer files and the sixth viewer assigned files (i.e., the review was mostly blind). We used the data to compare the total number of events scored per viewer, event confidence agreement, and event identification agreement among viewers.

Table 1. DIDSON camera deployments by site, orientation, number of hours of imagery collected and watched by day and night in 2011 at Bonneville Dam.

		Data collected (h)			Data watched (h)			Data watched (%)		
Site	Orientation	Day	Night	Total	Day	Night	Total	Day	Night	Total
CI	Landscape	106.4	88.2	194.6	1.0	6.1	7.1	0.9%	6.9%	3.6%
JP	Landscape	92.9	82.1	175.0	5.2	11.1	16.3	5.6%	13.5%	9.3%
NDE	Landscape	96.2	69.5	165.7	10.7	19.3	30.0	11.1%	27.8%	18.1%
NUE	Landscape	11.8	17.0	28.8	4.0	11.7	15.7	33.9%	68.8%	54.5%
SDE	Landscape	114.4	71.7	186.1	8.8	18.5	27.3	7.7%	25.8%	14.7%
SUE	Landscape	92.3	53.9	146.2	8.5	17.7	26.2	9.2%	32.8%	17.9%
JP	Portrait	32.2	30.8	63.0	1.2	3.1	4.3	3.7%	10.1%	6.8%
NDE	Portrait	126.8	87.1	213.9	11.8	26.7	38.5	9.3%	30.7%	18.0%
SDE	Portrait	31.2	28.6	59.8	8.9	15.3	24.2	28.5%	53.5%	40.5%
SUE	Portrait	102.4	77.9	180.3	13.9	24.5	38.4	13.6%	31.5%	21.3%

Depth estimation

To estimate lamprey depth in relation to the water surface, we used range and angle data from a subset of ~250 lamprey events scored in portrait mode from a camera deployed at a known depth. Depth was calculated using a sin function that accounted for both the angle of the DIDSON deployment and the angle of the event scored. The first detection location for each event was used to summarize the depth data as there was little difference between mean first and last detection locations (see Results). Depths were also calculated separately for events that occurred during normal and reduced fishway velocity conditions.

Environmental variables

Prior studies have indicated that high water velocities at fishway entrances impede lamprey passage, and operations at Bonneville Dam have been implemented to reduce velocities at night in an effort to improve passage conditions (Johnson et al. 2012). Water velocities at entrances to the Washington–shore PH2 fishway are determined by differences in elevation (head) between the inside of the fishway entrance and the dam tailrace. Head at PH2 fishway entrances was controlled by operation of two turbines (“fish units”) that provided water to the fishway collection channel. Velocities corresponding to operational criteria thought to be optimal for upstream migrating salmonids (> 1.98 m/s; 0.46 m of head) occurred during daytime hours throughout the DIDSON deployment period. Each night, typically between 2200 and 0400 hours, fish units were operated at reduced capacity producing fishway velocities (~1.2 m/s; 0.15 m of head). Reduced velocities were split into two categories: one for when minimum flow from both fish units exceeded 2 kcfs (reduced >= 2) and a second when flow from both units was less than 2 kcfs (reduced < 2). Standby conditions (~zero head and velocity) occurred intermittently when fish units were turned off to float debris off the fish unit trash racks, as required by operations guidelines. Lamprey event scoring was compared among operational conditions.

Results

Sampling effort

From 6 June through 2 September 2011, a total of 1,413 h of data were collected at Bonneville Dam (Table 1). Imagery was collected throughout the period of the lamprey run (Figure 3). Of the 1,413 h of data collected, 607 h (43%) were collected at night and 806 h (57%) were collected during the day. Most of the data (63%) were collected with the camera in a landscape orientation. Data collected between 6 August – 2 September were primarily in the portrait configuration (Figure 3). A total of 228 h of data was watched (16% of total collected) consisting of 122.6 h of landscape files (54%) and 105.4 h of portrait files (46%). The majority of the files watched (68%) were collected at night.

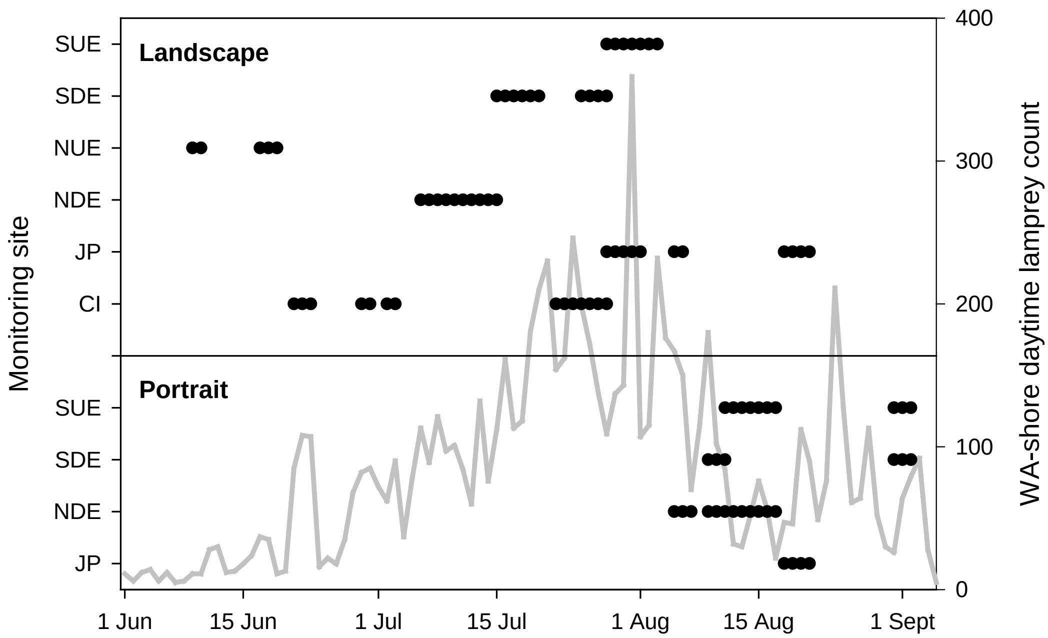

Figure 3. Dates of DIDSON camera deployment (black dots) at monitoring sites in landscape and portrait mode and daytime lamprey counts in 2011.

Lamprey events and confidence level

The rate at which lamprey were observed varied by location and camera orientation/season (Tables 2 and 3). The highest event rates were at SUE in both camera orientations/time periods. Rates at other locations varied considerably between camera orientations. The relative confidence also varied between camera orientations at many sites. For instance, the majority of lamprey targets were scored with high confidence at JP when in landscape mode but with low confidence when in portrait mode (Tables 2 and 3).

Table 2. Number of hours watched, total events, events/h and events by confidence class during landscape DIDSON deployments in 2011 at Bonneville Dam.

Landscape	Junction Pool (JP)	North Downstream Entrance (NDE)	North Upstream Entrance (NUE)	South Downstream Entrance (SDE)	South Upstream Entrance (SUE)
Files watched	977	180	93	162	157
Hours	16.3	30.0	15.7	27.3	26.2
Events (total)	37	333	106	465	877
Events/h	2.3	11.1	6.8	17.0	33.5
Confidence class					
Low	7 (19%)	71 (21%)	38 (36%)	70 (15%)	125 (14%)
Medium	7 (19%)	95 (29%)	35 (33%)	126 (27%)	192 (22%)
High	23 (62%)	167 (50%)	33 (31%)	269 (58%)	560 (64%)

Table 3. Number of hours watched, total events, events/h and events by confidence class during portrait DIDSON deployments in 2011 at Bonneville Dam.

Portrait	Junction Pool (JP)	North Downstream Entrance (NDE)	South Downstream Entrance (SDE)	South Upstream Entrance (SUE)
Files watched	25	231	144	226
Hours	4.3	38.5	24.2	38.4
Events (total)	20	140	45	270
Events/h	4.7	3.6	1.9	7.0
Confidence class				
Low	14 (70%)	63 (45%)	18(40%)	83(31%)
Medium	6 (30%)	32 (23%)	9 (20%)	63 (23%)
High	0 (0%)	45 (32%)	18 (40%)	124 (46%)

Fishway discharge patterns

Water velocities at entrances to the Washington–shore PH2 fishway were characterized predominantly by normal conditions during daytime hours (92% of time) while conditions at night thought to be optimal for lamprey passage (reduced >=2 and reduced <2) occurred 60% of the time (Tables 2-3). Standby conditions occurred intermittently during the season and accounted for less than 5% of the total operation criteria during the sampling period.

Among-viewer comparison

A total of 69 files (11.5 h) of DIDSON files were all watched by six viewers, including 38 landscape files and 31 portrait files (Table 4). Between 3 and 60 total lamprey events were scored in each site-orientation combination. The highest number of total events, events per viewer, and events/h were recorded at SUE for both landscape and portrait modes. Given that only 3 events were scored in the JP portrait deployment (all low confidence), this site was excluded from subsequent analyses.

Among-viewer event agreement was generally higher in landscape mode than in portrait mode, but was highly variable in both camera orientations. For example, a total of 60 lamprey events were identified in the SUE landscape files, but only 24 (40%) were identified by all viewers (Figure 4). Forty events were identified in the SUE portrait files, with just 7 (18%) identified by all viewers (Figure 5). Events identified by all viewers in the other deployments were: 25% (SDE landscape), 10% (NDE landscape), 7% (NUE landscape), 13% (SDE portrait), and 3% (NDE portrait). At all sites, viewer event agreement tended to increase as confidence level increased (Figure 6). For example, in the NDE landscape files, median among-viewer event agreement was 35% when all confidence levels were included but increased to 71% when only high confidence events were included. Patterns were similar across sites (Figure 6).

Among-viewer agreement in the total number of lamprey events per deployment also varied considerably, although there was gross-scale agreement. All viewers scored more lamprey events in the SUE landscape mode and fewer events in the SDE portrait mode, for example, than in all other deployments (Figure 7). Variability among viewers (i.e., the range in total scores) decreased when low confidence events were excluded in five of the seven deployments. The exceptions were SDE and SUE landscape deployments.

Table 4. Summary of the files reviewed in the multi-viewer quality control evaluation. Total events = unique lamprey events of all confidence levels, with all viewers' scoring combined.

			View	Total	Events per viewer		Events/h	
Site	Orientation	Dates	time (min)	events	Mean	Range	Mean	Range
JP	Landscape	5	80	3	1	0-1	0.8	0.0-0.8
NDE	Landscape	5	70	48	18	11-41	15.4	9.4-35.1
NUE	Landscape	3	70	30	12	6-20	10.3	5.1-17.1
SDE	Landscape	6	90	55	30	20-41	20.0	13.3-27.3
SUE	Landscape	4	70	60	40	32-47	34.3	27.4-40.3
NDE	Portrait	9	140	30	9	3-18	3.9	1.3-7.7
SDE	Portrait	3	70	8	3	1-7	2.6	0.9-6.0
SUE	Portrait	6	100	40	19	11-24	11.4	6.6-14.4

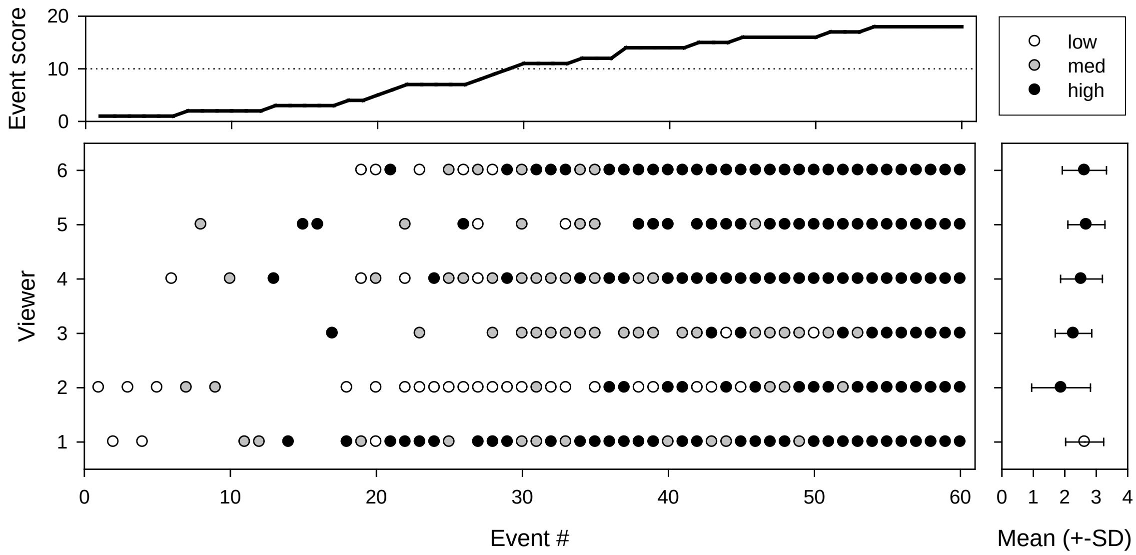

Figure 4. Lamprey event scoring by six viewers at the south upstream entrance (SUE) collected during 70 minutes of landscape mode ranked by increasing agreement for each event. Scores were: 1 for low (○), 2 for medium (●), and 3 for high (●) confidence. Top panel is the sum of confidence scores for each event across viewers, with a maximum value of 18. Right panel shows the mean (+/- SD) score for each viewer. Note that there was considerable variability in event identification and event confidence among viewers, but also greater among-viewer event agreement as confidence increased.

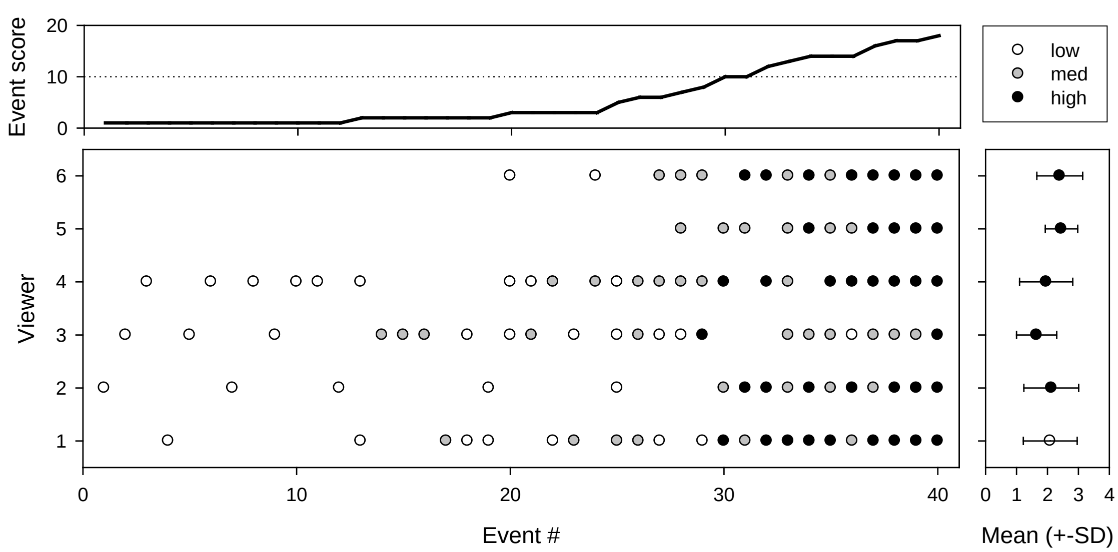

Figure 5. Lamprey event scoring by six viewers at the south upstream entrance (SUE) collected during 100 minutes of portrait mode ordered by total score. Scores were: 1 for low (○), 2 for medium (●), and 3 for high (●) confidence. Top panel shows the total score for each event. Right panel shows the mean (+/- SD) score for each viewer. A total of 40 events were identified, including 7 (18%) that were identified by all viewers. Note that there was considerable variability in event identification and event confidence among viewers, but also greater among-viewer event agreement as confidence increased.

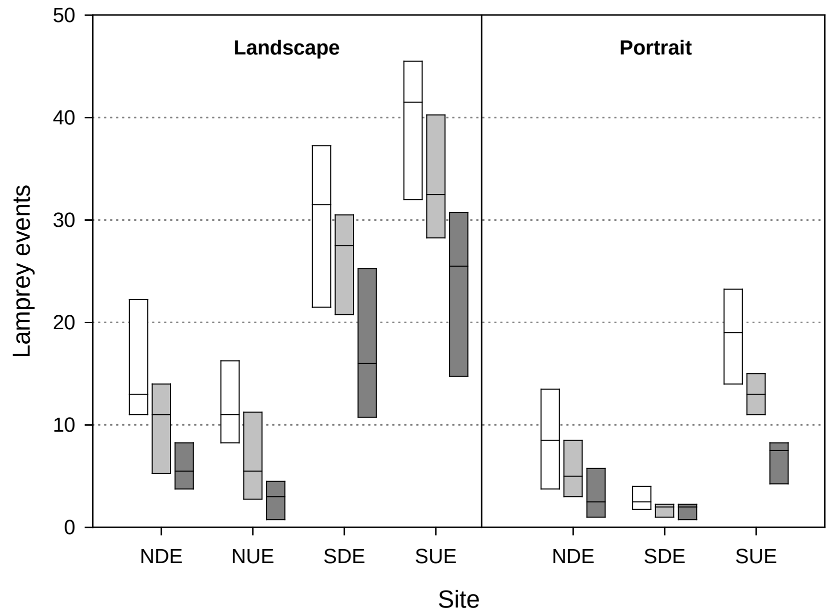

Figure 6. Among-viewer (n =6) agreement on lamprey event identification. Box plots (10th, 25th, 50th, 75th, and 90th percentiles) show agreement for 15 pairs of viewers at each site and deployment. White boxes include all low, medium and high confidence events. Light gray boxes: all medium and high events. Dark gray boxes: high events only. Note that event agreement increases with viewer confidence. Including low confidence events in DIDSON scoring probably results in overestimates of lamprey abundance, but including only high confidence events probably results in underestimates.

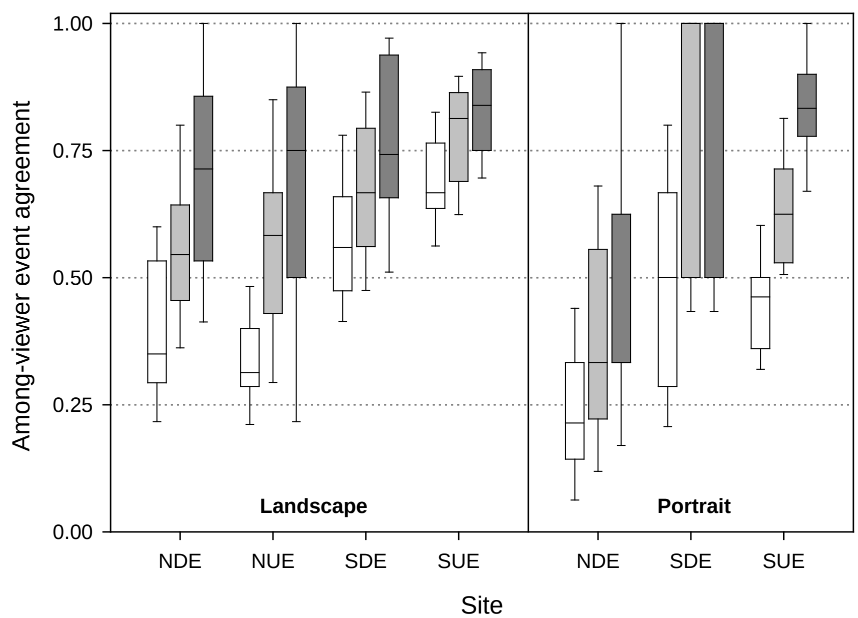

Figure 7. Box plots (25th, 50th, 75th percentiles) of the numbers of lamprey events per viewer (n = 6) at each deployment and site. White boxes include all low, medium and high confidence events. Light gray boxes: all medium and high events. Dark gray boxes: high events only.

Due to differences in camera depth and orientation imposed by the locations and lengths of available I-beams, we focused on analyses of behavior at individual sites rather than across site comparisons. Below, we present results for each site.

South upstream entrance (SUE) landscape

The SUE entrance was included in the evaluations because we have observed high exit rates at this location in the past. From 28 July – 3 August a total of 146 h of data were collected at the Washington–shore PH2 south upstream entrance (SUE) in landscape orientation and 26.2 hours of imagery (18% of total collected) were reviewed (Table 1; Appendix B Figure 1). Of the imagery watched 8.5 h was collected during the day (9% of total day imagery collected) and 17.7 h was collected at night (33% of total night imagery collected).

Event rate – Eight hundred seventy-seven lamprey events were scored (33.5 events/h). Sixty-four percent of the events were scored high confidence, 22% were medium, and l4% were low confidence (Table 2).

Most lamprey events (90%) occurred at night (Figures 8-9). A slightly higher proportion of lamprey were classified with medium and high confidence at night (86%) compared to the day (79%) (Figure 8). Throughout the day, the largest percentage of events was observed during normal operating conditions (there was only limited reduced velocity conditions during daytime hours). The number of events/h during the day was 11.6 (normal) and 4.8 (standby). Event rate at night was also higher during normal operations (60.3) but did not differ between the reduced conditions (38.0-40.8). The number of lamprey events/h with sturgeon present was lower during the day (4.8 with sturgeon and 11.9 without sturgeon) but not at night (46.7 with sturgeon and 43.0 without sturgeon) (Figure 8).

Net upstream movement – The majority of movements were upstream during both night (57 %) and day (67%; Figure 10). Downstream movement was 27% at night and 24% during the day. No net movement was observed in 16% of the nighttime and 9% of the daytime events, typically when lampreys entered and exited the sample volume from above or below rather than from the up- or downstream boundaries. Net downstream movement was associated with decreased lamprey scoring confidence, perhaps because movement velocities and observation durations were shorter than for upstream movements. Net downstream movement patterns were similar across velocity conditions at night (Figure 10). Few lamprey movements were recorded outside normal conditions during daytime (n = 6 for standby conditions). Net upstream and downstream movement changed little with the presence of sturgeon (Figure 10). Lamprey generally oriented into the prevailing flow (heading) regardless of the direction of movement (Figure 11).

Event duration – Lamprey moved rapidly through the sample volume during most events. Median time that lampreys were in the camera FOV (field of view) was 2.4 s during the day and 2.6 s at night (Figure 12). Confidence level increased with event duration. Lampreys classified with low confidence were in the FOV ranging from 1.7 s (median night) to 1.9 s (median day) and those classified high confidence were in the FOV a median of 3 s. There was little difference in how long lamprey were in the FOV relative to fishway water velocity.

Lateral distribution – We observed a larger number of lamprey in the middle of the sample window (Figure 13). Between 75-89% of the lamprey observed were between 3.5-6 m of the camera. We note that the sample volume increased with increasing distance from the DIDSON, and thus the true distributions was likely shifted slightly to the left compared to the distributions depicted in Figure 13.

Prevalence of attachments – Between 4% (night) and 10% (day) of the lamprey were observed attached to a fishway structure (Figure 14). Most attachments occurred during normal operating conditions (100% during the day and 78% at night) and most fish attached to a fishway wall. We observed a higher prevalence of attachment when sturgeon were not present.

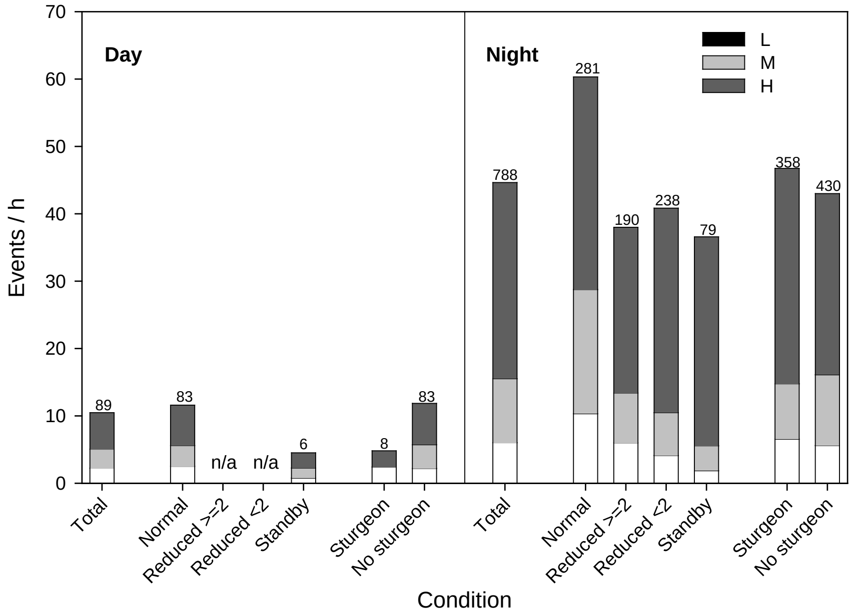

Figure 8. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at SUE during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

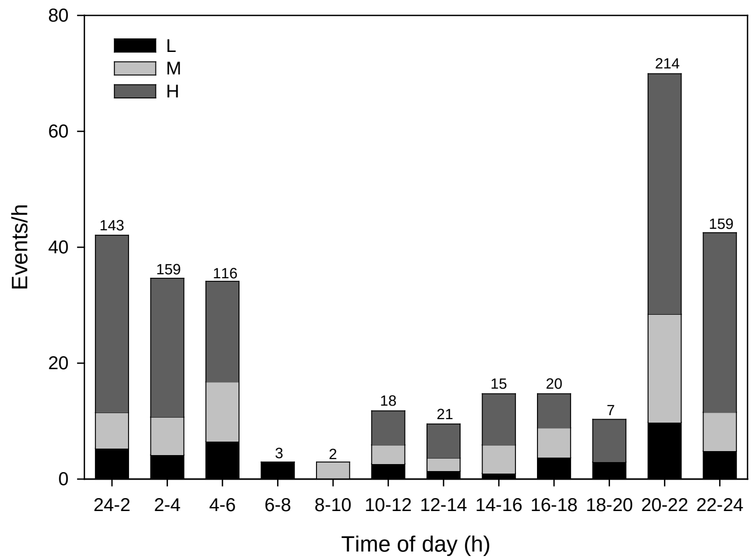

Figure 9. Number of events per hour by time of day at SUE during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

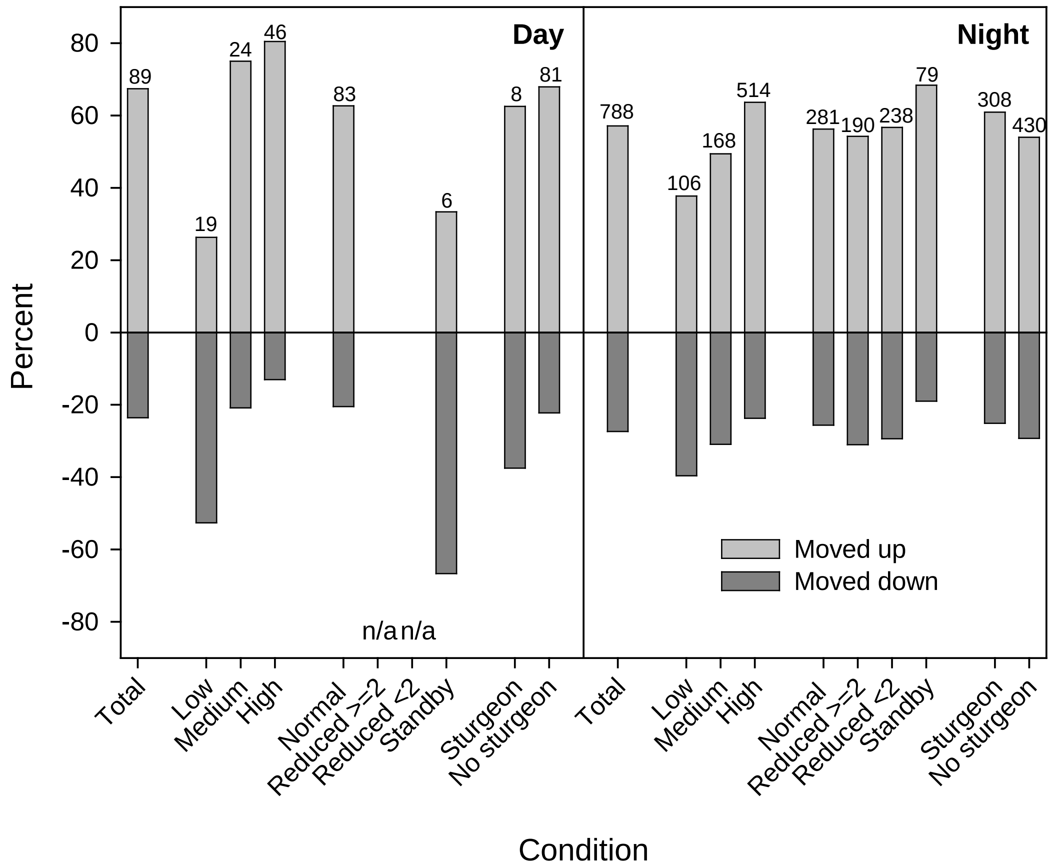

Figure 10. Percent of net movement upstream or downstream by day, night, velocity conditions, and presence or absence of sturgeon at SUE during landscape DIDSON deployment. Sample sizes are above each bar.

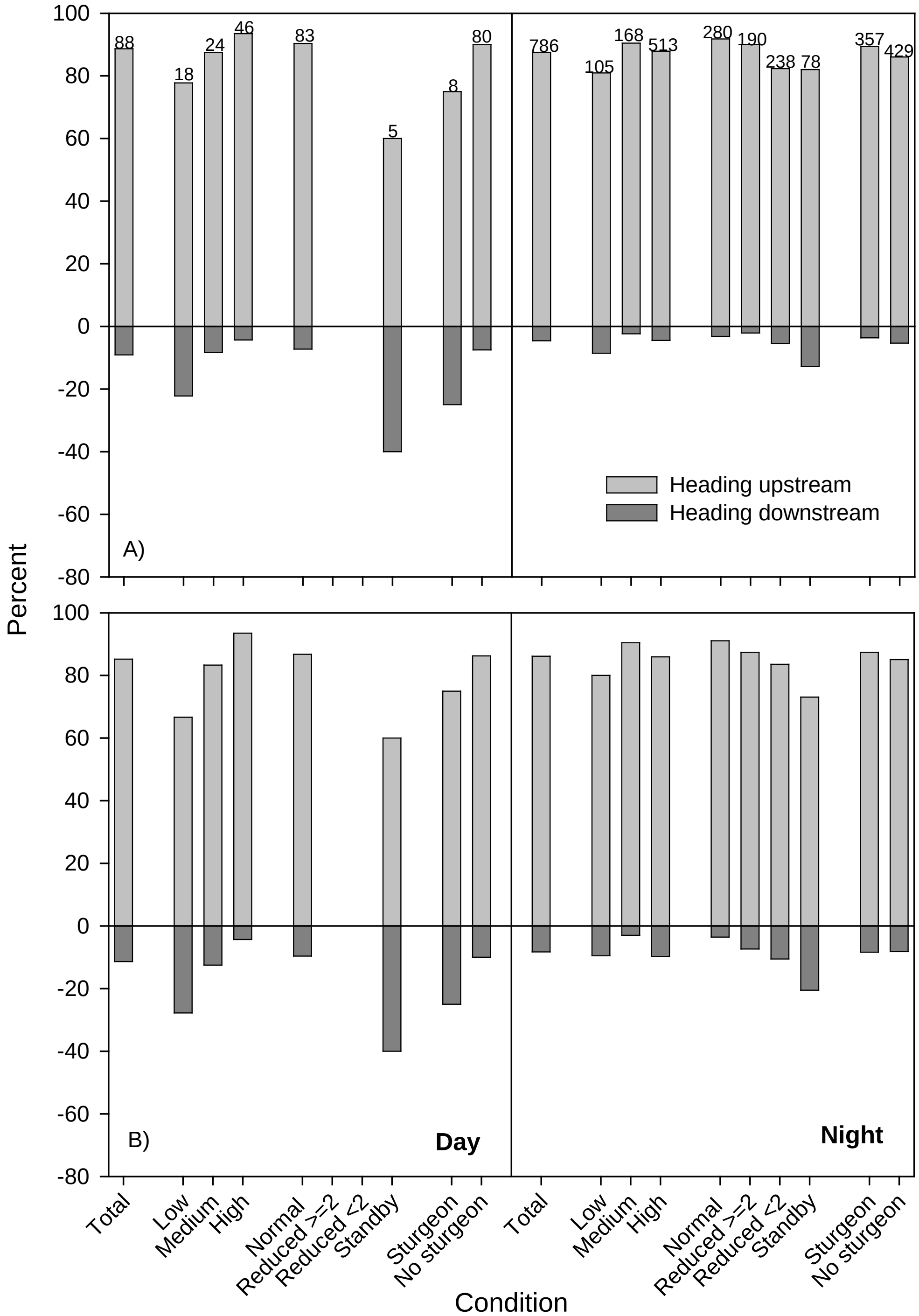

Figure 11. Percent of time a lamprey's orientation was upstream or downstream by day, night, velocity conditions, and presence or absence of sturgeon at SUE during landscape DIDSON deployment. Sample sizes are above each bar. Orientation in beginning of event A) and orientation at end of event B).

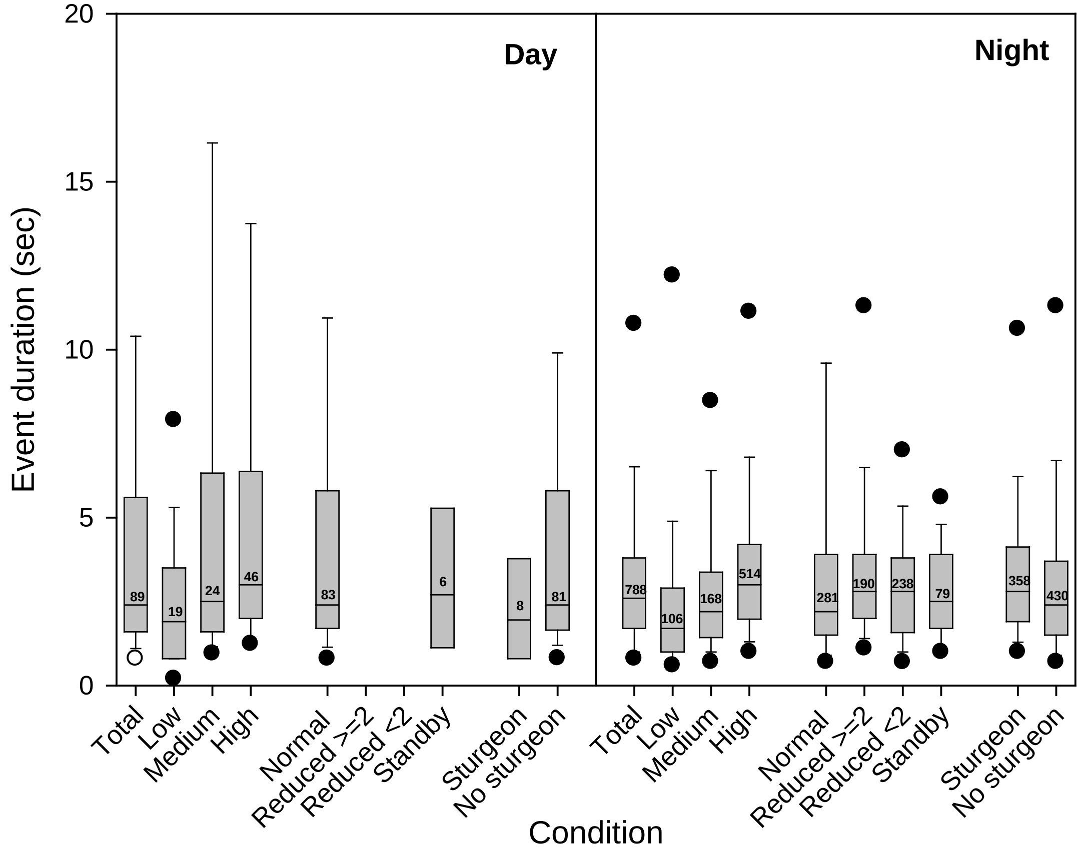

Figure 12. Duration of each lamprey event by day, night, velocity conditions, and presence or absence of sturgeon at SUE during landscape DIDSON deployment. Sample sizes are shown on each bar.

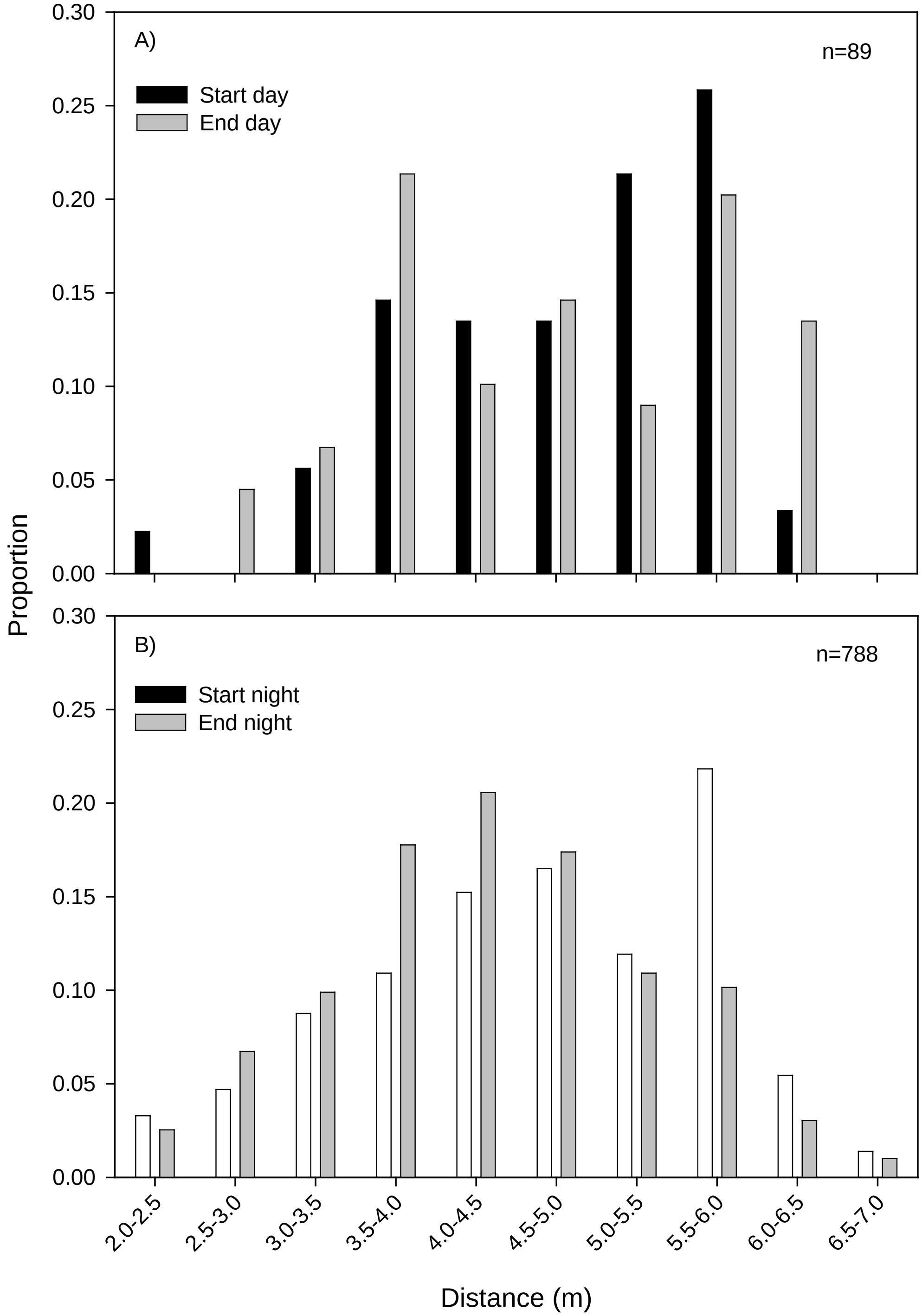

Figure 13. Proportion of lamprey events by distance from camera at the start and end of each event at SUE during landscape DIDSON deployment. A) day events and B) night events. Total Sample sizes are shown on each graph. The fishway wall was located between 2 and 6-7 m in the FOV. Note that the FOV was smaller closer to the camera.

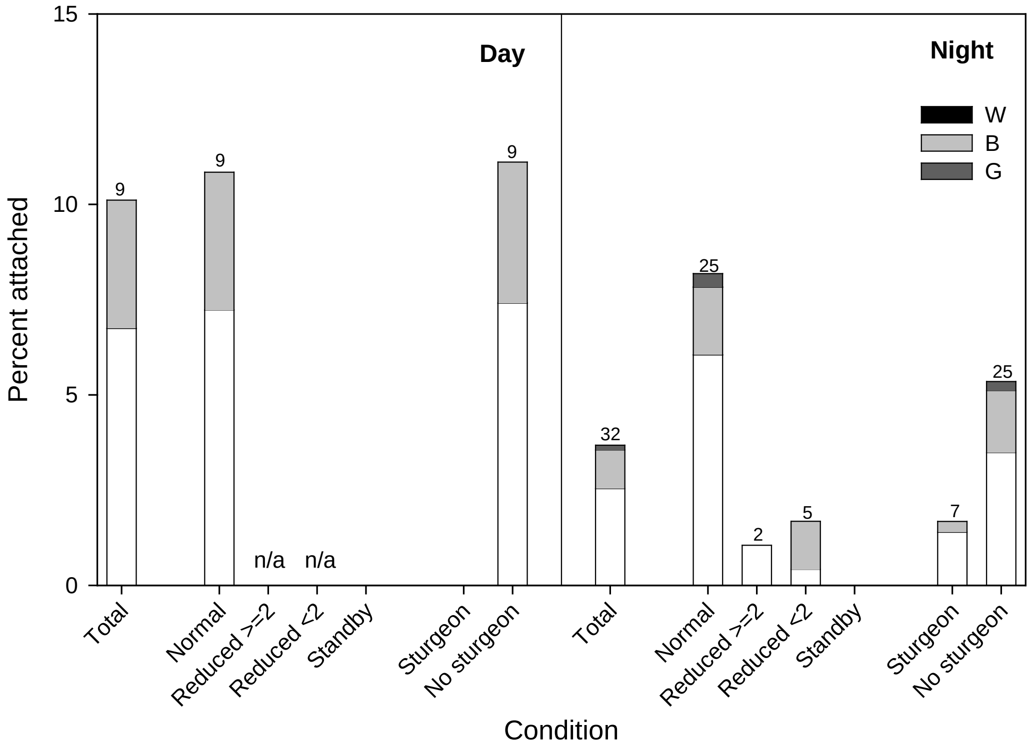

Figure 14. Percent of lamprey that attached by day, night, velocity conditions, and presence or absence of sturgeon at SUE during landscape DIDSON deployment. Bars are stacked by attachment location wall (W), bulkhead slot (B), and Gate (G). Sample sizes are shown on each bar.

South upstream entrance (SUE) portrait

A total of 180 h of data were collected at the Washington–shore PH2 south upstream entrance (SUE) in portrait orientation (11-17Aug and 31 Aug-2 Sep) and 38 hours of imagery (21% of total collected) were reviewed (Table 1; Appendix B Figure 2). Of the imagery reviewed, 13.9 h was collected during the day (14% of total day imagery collected) and 24.5 h was collected at night (32% of total night imagery collected).

Event rate by fishway operation and time of day – Two hundred- seventy events were documented (7.0 events/h). Forty-six percent of the events were scored high confidence, 23% were scored medium, and 31% with low confidence (Table 3).

Most lamprey observations (91%) occurred at night (Figures 15-16) and a higher percentage of lamprey events were classified high confidence at night. The percentage of lamprey classified as high, medium, and low confidence were similar for lamprey observed during the day (Figure 15). The event rate was highest during normal operations (16 events/h) and reduced >=2 operations (14.2 events/h). The event rate was lower during the day and few events were observed outside normal operations. The number of lamprey events/h did not differ with sturgeon presence during the day and were slightly higher at night with sturgeon absent (Figure 15).

Event duration by location and time of day – The median time that lamprey were in the camera FOV ranged from 2.4 s during the day to 2.6 s at night (Figure 17). Median duration for fish that attached was 74 s. Lamprey classified with low confidence were in the FOV ranging from 2.4 s (median day) to 2.1 s (median night) and those classified high confidence were in the FOV for 1.3 s (median day) and 2.8 s (median night). There was no difference in time in the FOV relative to velocity condition.

Lateral distribution – We observed more lamprey at mid and far ranges across the entrance compared to near ranges during the day, reflecting the increased sample volume with range (Figure 18). At night lamprey were more evenly distributed throughout the range.

Prevalence of attachments – The percent of lamprey observed attaching to a fishway structure was 2%. The 8 total attachment events occurred (7 at night and 1 during the day) with the majority of lamprey attaching to the wall.

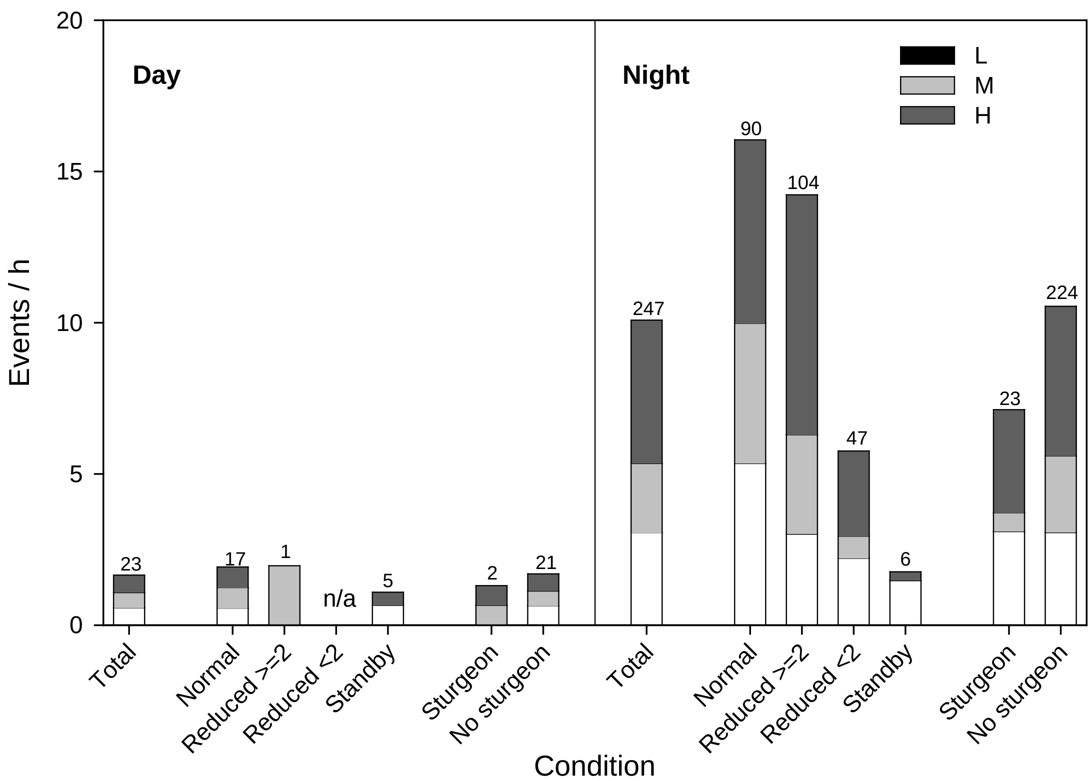

Figure 15. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at SUE during portrait DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

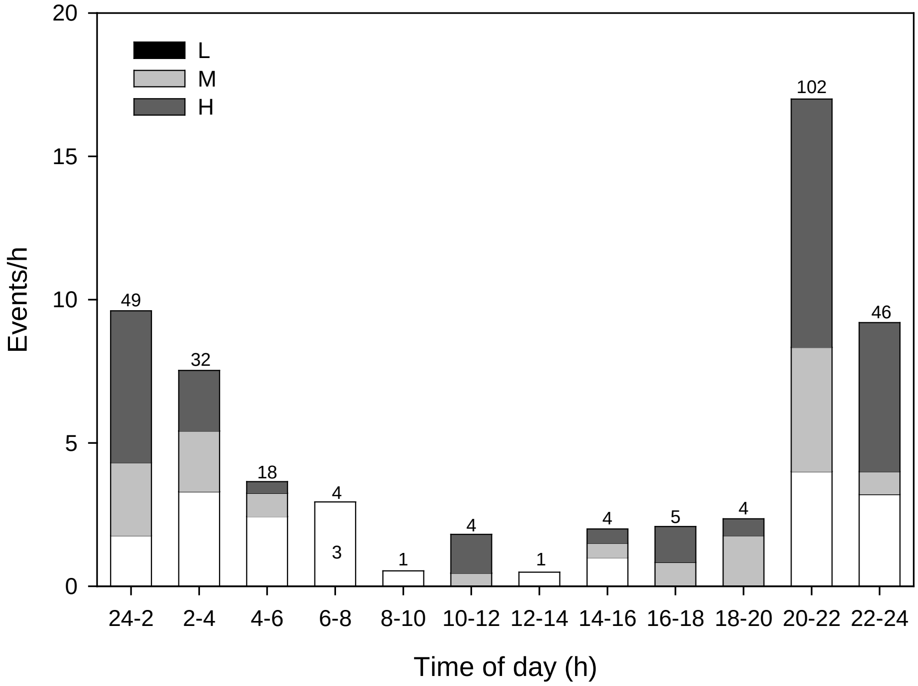

Figure 16. Number of events per hour by time of day at SUE during portrait DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

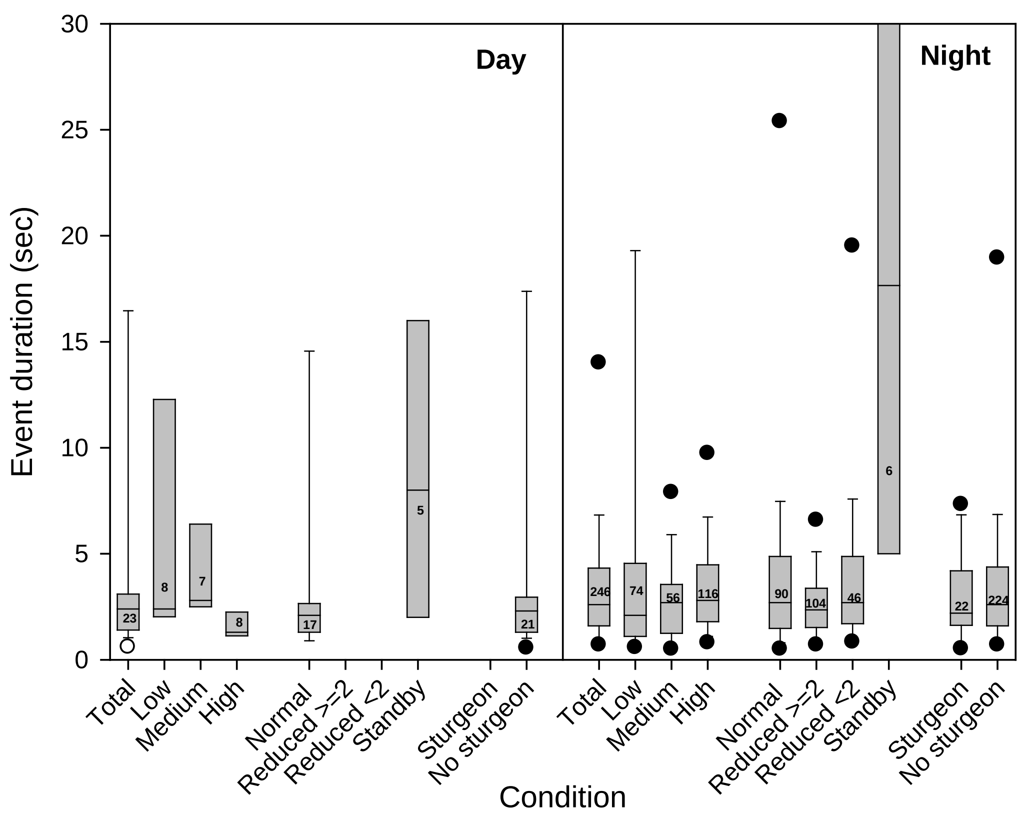

Figure 17. Duration of each lamprey event by day, night, velocity conditions, and presence or absence of sturgeon at SUE during portrait DIDSON deployment.. Sample sizes are shown on each bar.

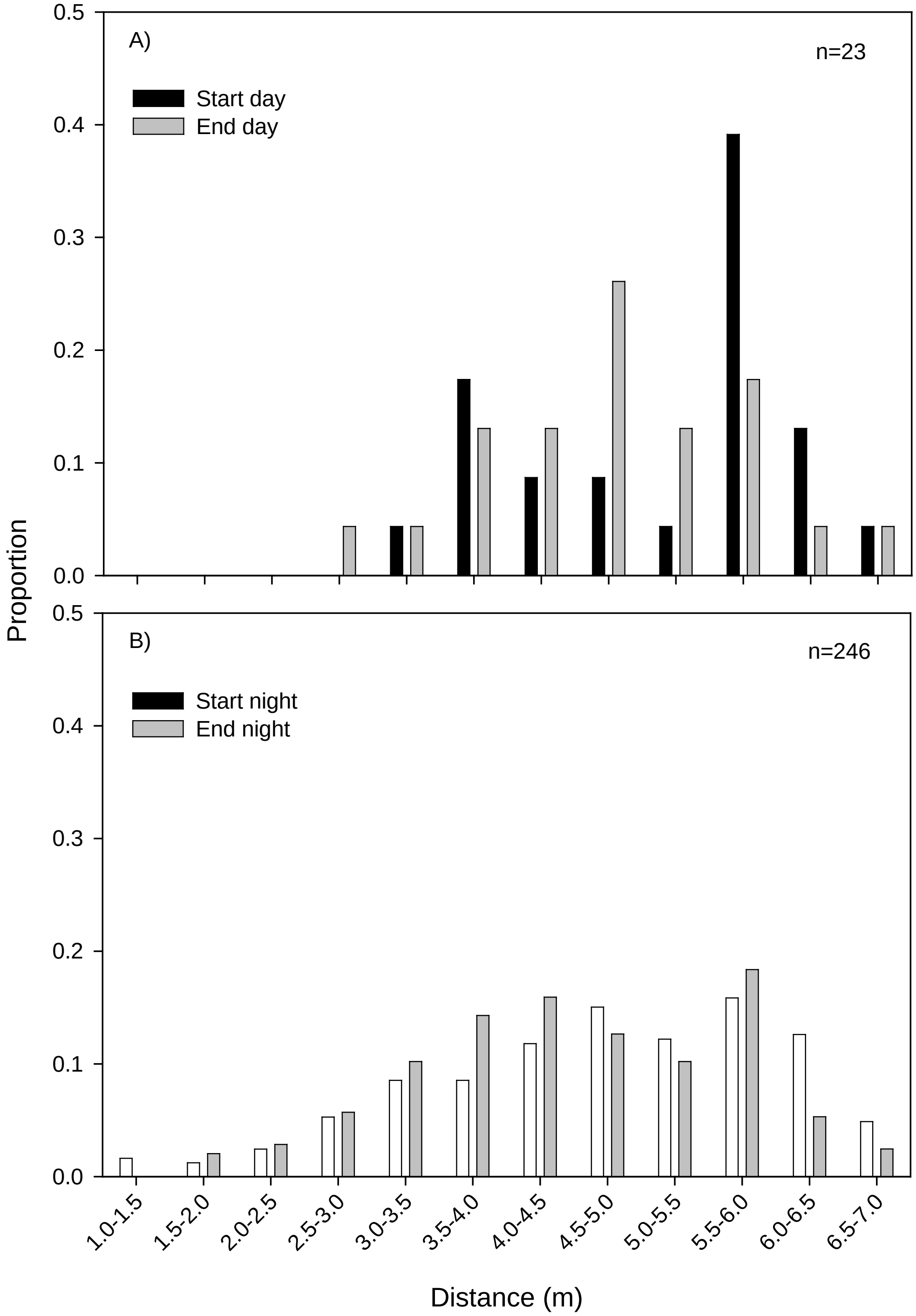

Figure 18. Proportion of lamprey events by distance from camera at the start and end of each event at SUE during portrait DIDSON deployment. A) day events and B) night events. Total Sample sizes are shown on each graph. The fishway wall was located between 1.7 and 6-7 m in the FOV. Note that the FOV was smaller closer to the camera.

South downstream entrance (SDE) landscape

Between 15 – 28 July a total of 186 h of data were collected at the Washington–shore PH2 south downstream entrance (SDE) in landscape orientation and 27.3 hours of imagery (15% of total collected) were reviewed (Table 1; Appendix B Figure 2). Of the imagery reviewed 8.8 h was collected during the day (8% of total day imagery collected) and 18.5 h was collected at night (26% of total night imagery collected). A total of 16.6 h of data was reviewed with the spreader lens and 10.7 h was reviewed without the spreader lens (see Appendix A).

Event rate –A total of 465 lamprey events were documented (17.0 events/h). Events/h were similar with (17.0) and without (16.9) the spreader lens and data from both deployments are combined in the following analyses. Fifty-eight percent of the events were scored high confidence, 27% scored medium confidence and 15% were scored low confidence (Table 2).

Most lamprey observations (83%) were at night and during normal operating conditions (78% night and 100% day) (Figures 19-20). There was little difference between the percentage of lamprey that were classified with medium and high confidence at night (86%) and the day (81%) (Figure 19). The number of events/h during the day that only occurred during normal conditions was 9.2. Event rate at night was higher during normal operations (24.9) and reduced>=2 (16.0). Fewer lamprey events/h occurred with sturgeon present at night (9.8 with sturgeon and 23.1 without sturgeon) but not during the day (Figure 19).

Net upstream movement – The percent of events with net upstream movement was 59% at night and 75% during the day (Figure 21). Thirty-four percent of the lamprey moved downstream at night and 19% moved downstream during the day. Seven percent of the night-time and 6% of daytime events were considered no net movement. Decreased confidence was associated with downstream movements. Net downstream movement decreased as flows increased at night (80% reduced<2, 38% reduced >=2 and 31% normal). Net upstream movement at night was 24% with sturgeon present compared to 61% without sturgeon (Figure 21). Net upstream or downstream movement did not differ with the presence or absence of sturgeon during the daytime. Lamprey generally oriented (heading) upstream regardless of the direction of movement except during reduced<2 conditions when 67% were oriented downstream (Figure 22).

Event duration – Median duration that lamprey were in the camera FOV was 2 s during the day and 2 s at night (Figure 23). Confidence of the target increased with duration. Lamprey classified with low confidence were in the camera FOV ranging from 1.2 s (median night) to 1.4 s (median day) and those classified high confidence were in the FOV a median of 2.5 s (night) and 2.7 s (day).

Lateral distribution – The proportion of lamprey observed increased with distance from the camera out to a distance of 5 m (Figure 24). Less than 6% were observed beyond ~ 5 m of the camera, which was where the downstream section of the wall appeared in the FOV (the upstream section of the fishway wall was at ~ 6 m).

Prevalence of attachments – The percentage of fish observed attaching to a fishway structure ranged from 5% (day) to 8% (night) (Figure 25). Attachments were observed across velocity treatments with more fish (12%) attaching at nighttime reduced>=2 operation. Most fish attached to the fishway bulkhead slot. We observed a higher prevalence of attachment when sturgeon were absent.

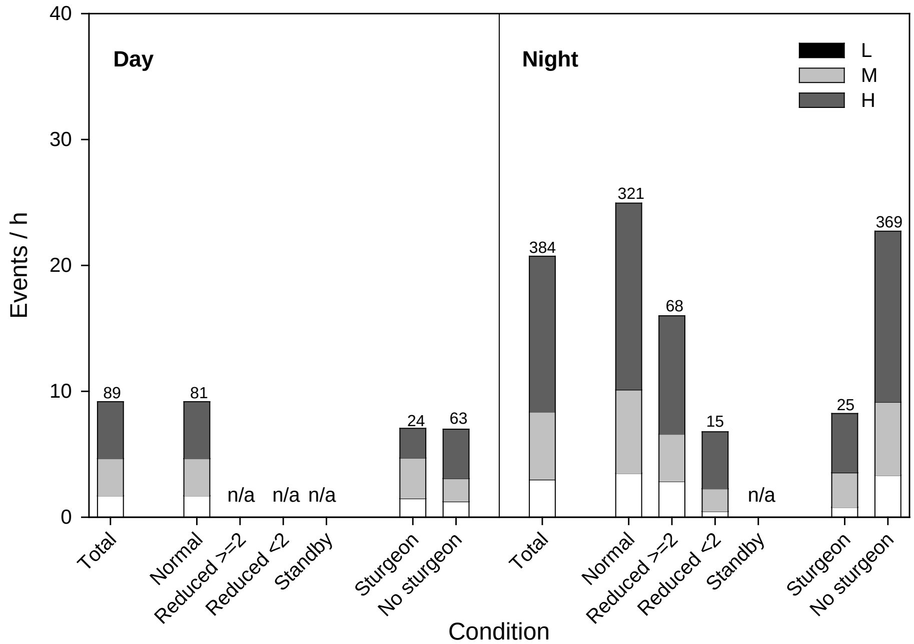

Figure 19. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at SDE during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

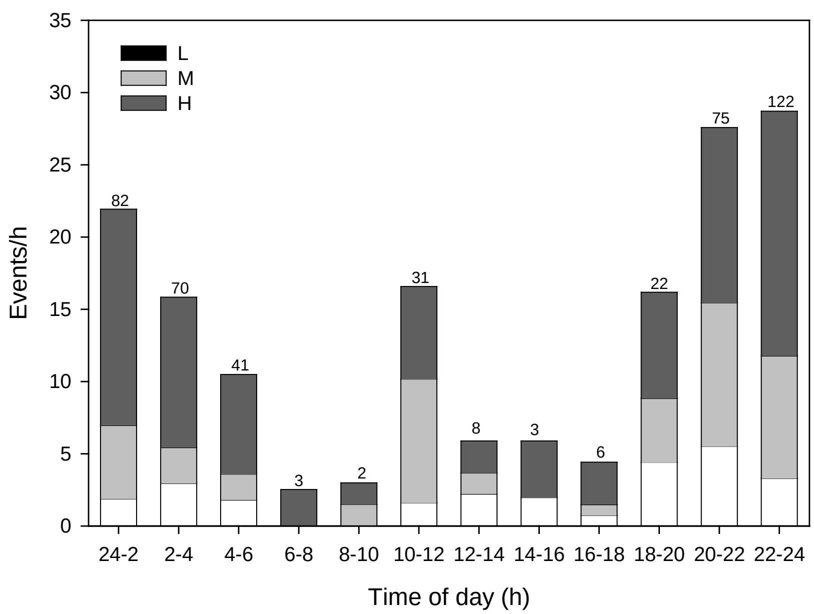

Figure 20. Number of events per hour by time of day at SDE during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

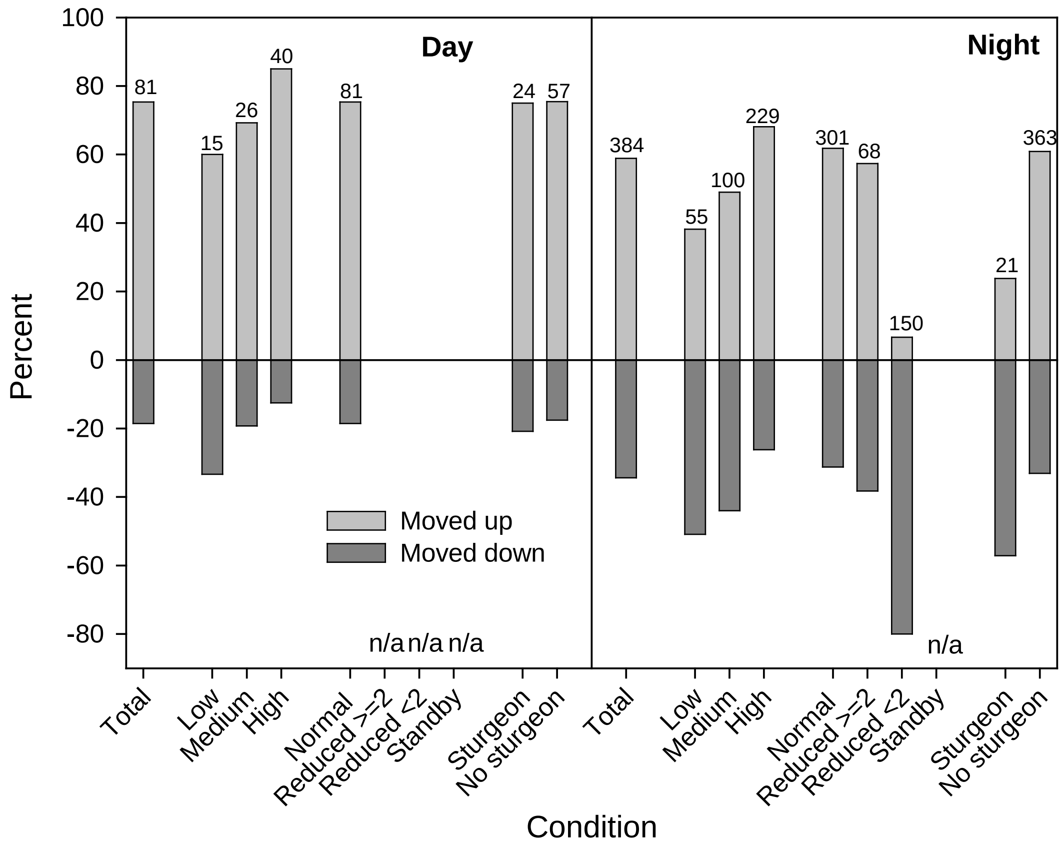

Figure 21. Percent of net movement upstream or downstream by day, night, velocity conditions, and presence or absence of sturgeon at SDE during landscape DIDSON deployment. Sample sizes are above each bar

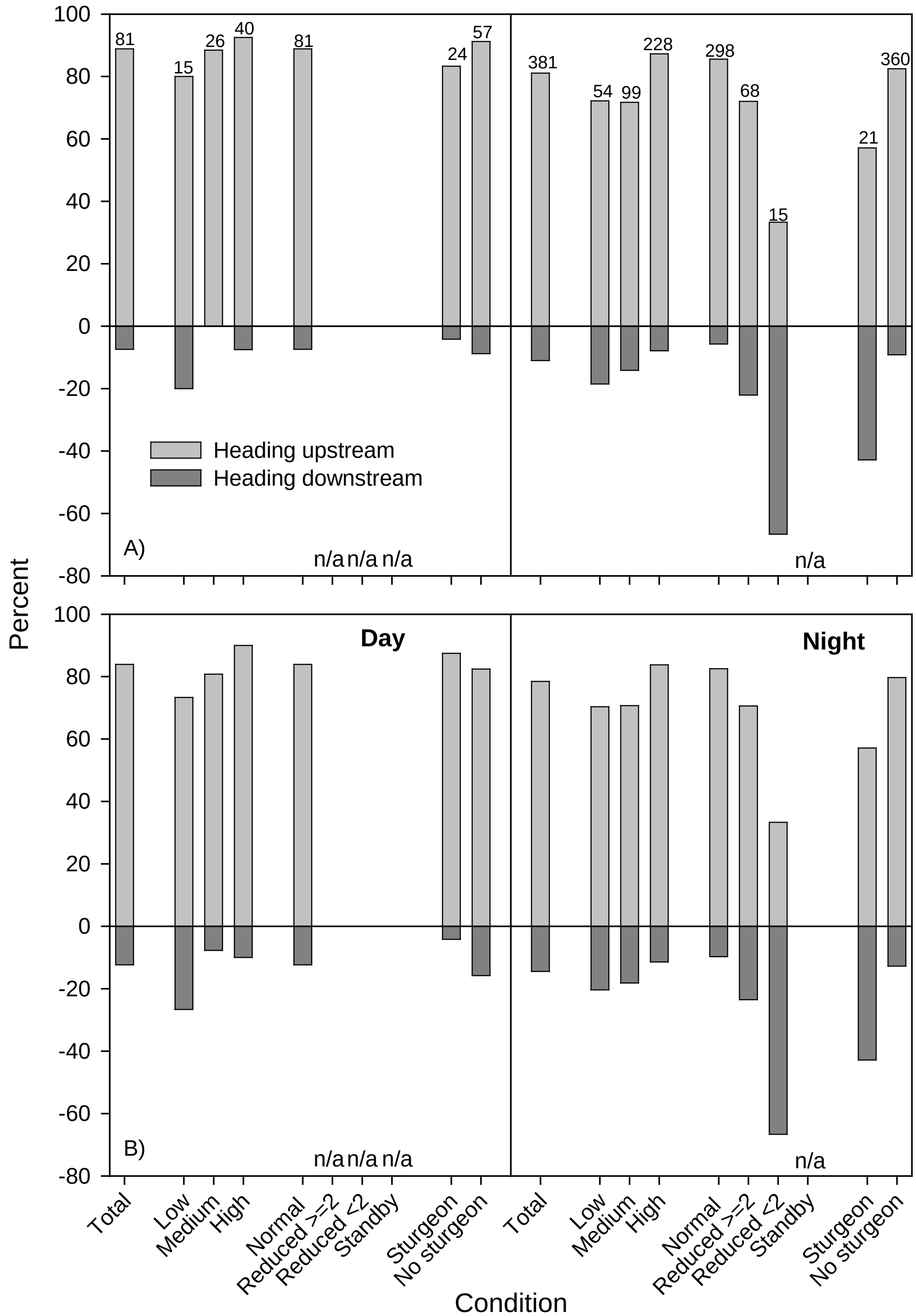

Figure 22. Percent of time a lamprey's orientation was upstream or downstream by day, night, velocity conditions, and presence or absence of sturgeon at SDE during landscape DIDSON deployment. Sample sizes are above each bar. Orientation in beginning of event A) and orientation at end of event B).

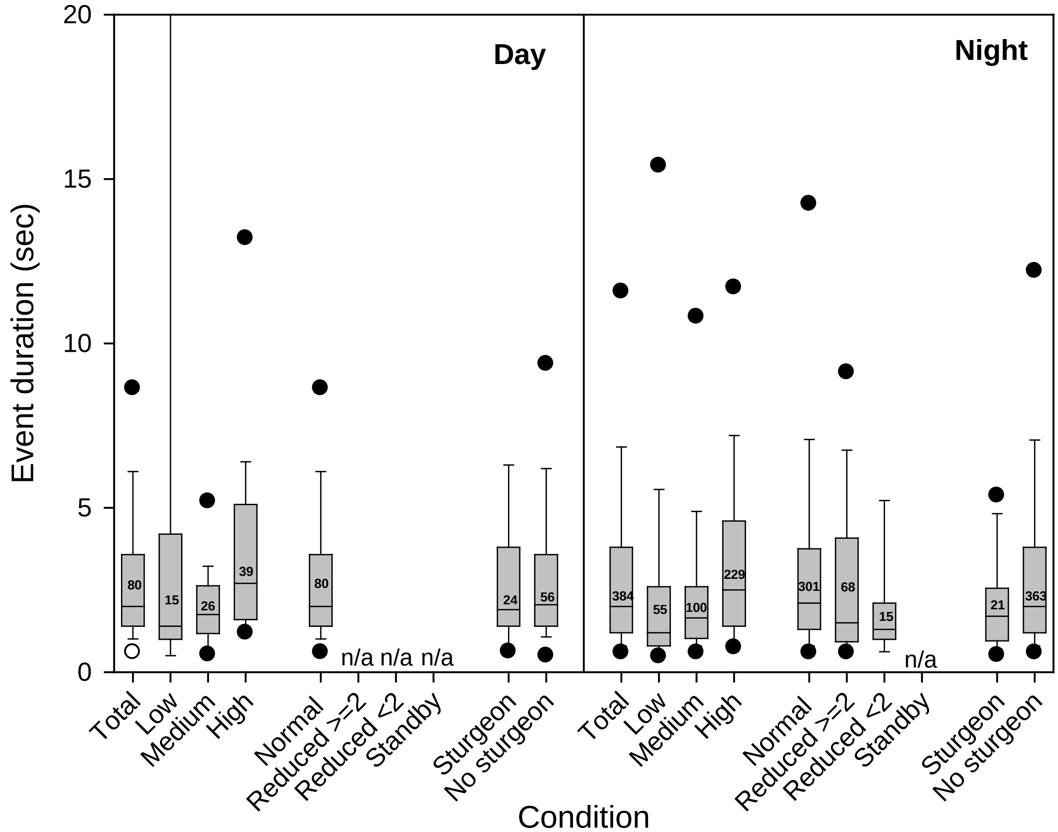

Figure 23. Duration of each lamprey event by day, night, velocity conditions, and presence or absence of sturgeon at SDE during landscape DIDSON deployment. Sample sizes are shown on each bar.

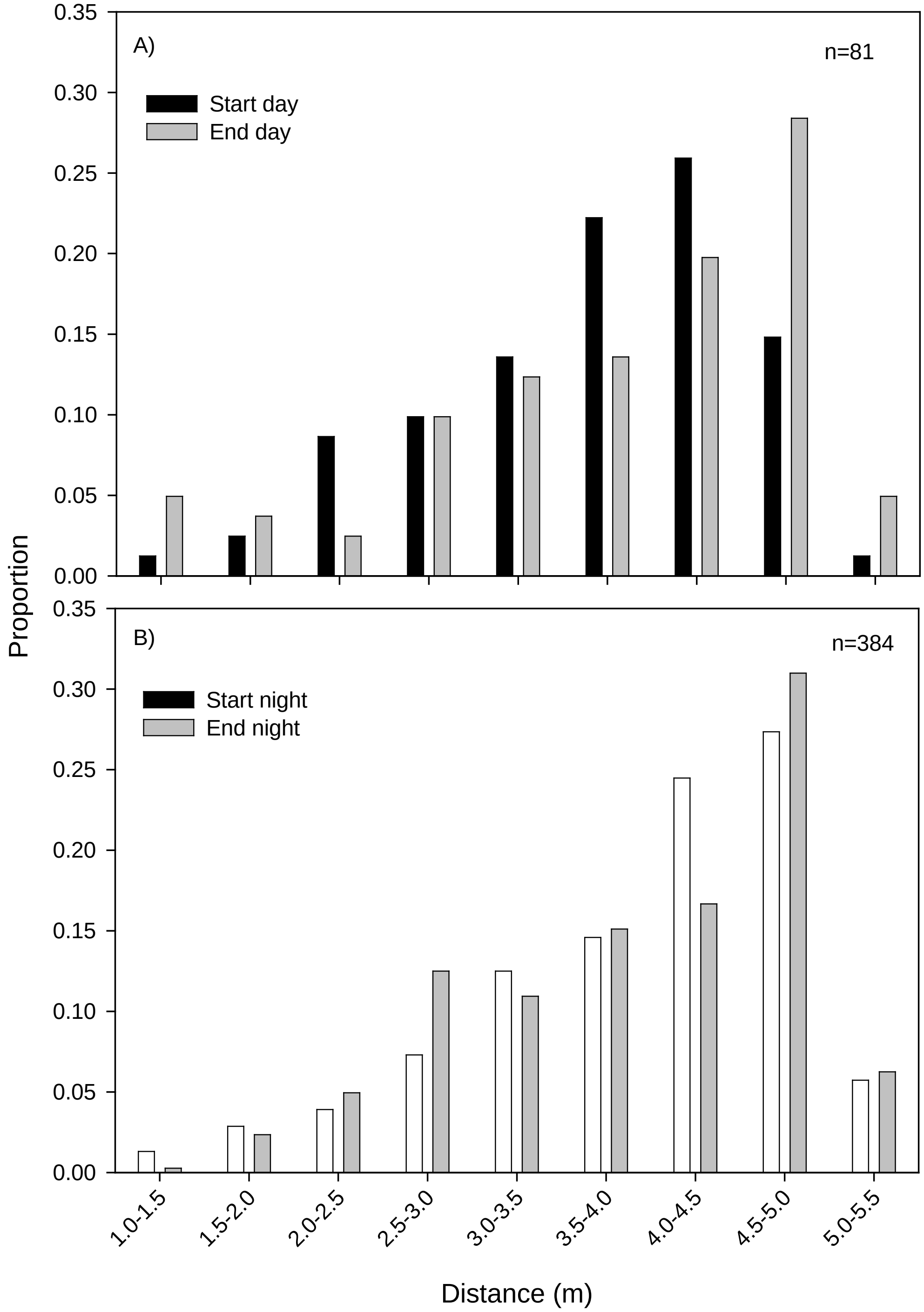

Figure 24. Proportion of lamprey events by distance from camera at the start and end of each event at SDE during landscape DIDSON deployment. A) day events and B) night events. Total Sample sizes are shown on each graph. The fishway wall was located between 1 and 5-6 m in the FOV. Note that the FOV was smaller closer to the camera.

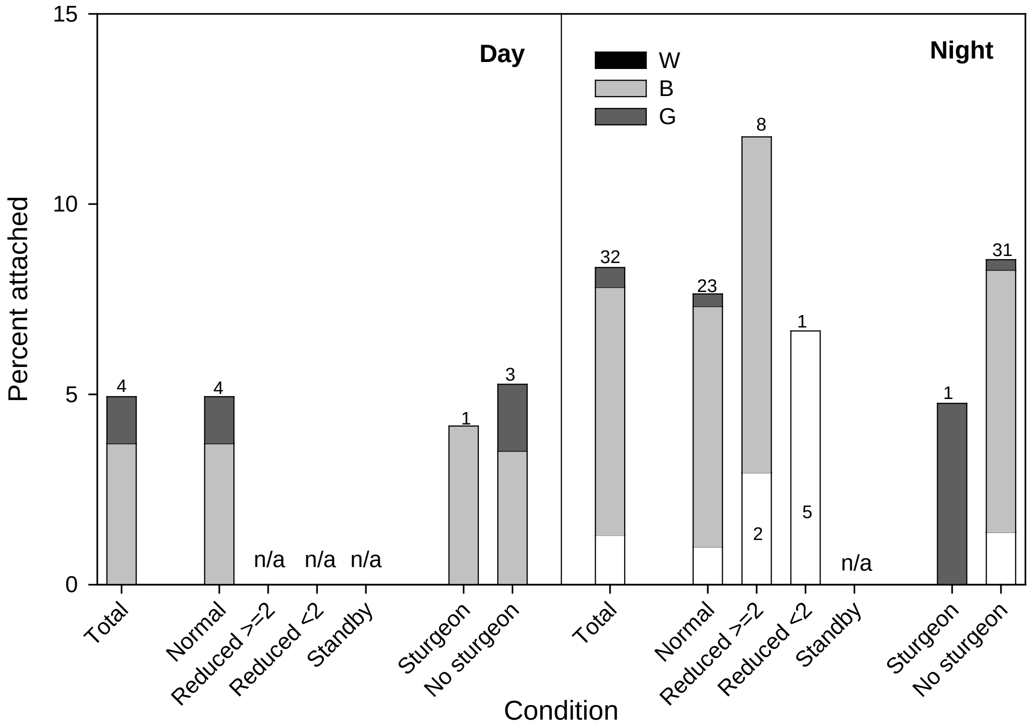

Figure 25. Percent of lamprey that attached by day, night, velocity conditions, and presence or absence of sturgeon at SDE during landscape DIDSON deployment. Bars are stacked by attachment location wall (W), bulkhead slot (B), and Gate (G). Sample sizes are shown on each bar.

South downstream entrance (SDE) portrait

A total of 144 h of data were collected at the Washington–shore PH2 south downstream entrance (SDE) in portrait orientation (31 Aug-2 Sep) and 24 hours of imagery (41% of total collected) were reviewed (Table 1; Appendix B Figure 2). Of the imagery reviewed 8.9 h was collected during the day (29% of total day imagery collected) and 15.3 h was collected at night (54% of total night imagery collected).

Event rate by fishway operation and time of day – Forty-five lamprey events were documented with varying confidence (1.9 events/h). Forty percent of the events were scored high confidence while 60% were scored low or medium confidence (Table 3).

Most lamprey movements (93%) occurred at night (Figures 26-27) with a higher percentage of lamprey classified as high confidence (43%) at night and low confidence (83%) during the day (Figure 26). The highest events/h at night were observed during normal (3.7) and reduced>=2 operations (2.5). The number of lamprey events/h was slightly higher at night with sturgeon present (Figure 26).

Event duration by location and time of day – Median duration of time lamprey were in the camera FOV was 1.5 s during the day and 2.0 s at night (Figure 28). Lamprey classified with low confidence were in the FOV a shorter time period (median 1.8 s day- median 1.4 s night) than those classified high confidence (median 2.1 s night). There was no difference in the duration of time lamprey occupied the FOV relative to velocity condition.

Lateral distribution – We observed more lamprey in the inner-middle ranges at night and in the middle range during the day although sample size was small (Figure 29). Between 67-80% of the nighttime lamprey observations were between 2.0-4.0 m of the camera.

Prevalence of attachments – No attachment events were observed at this site.

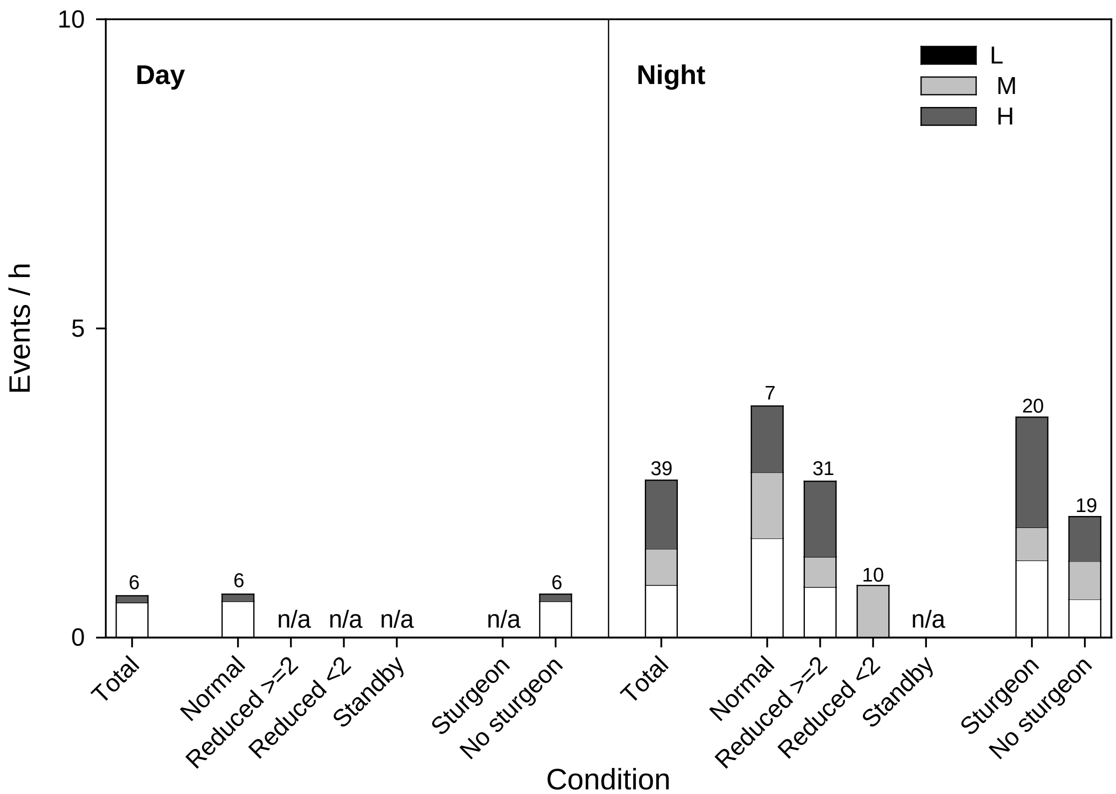

Figure 26. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at SDE during portrait DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

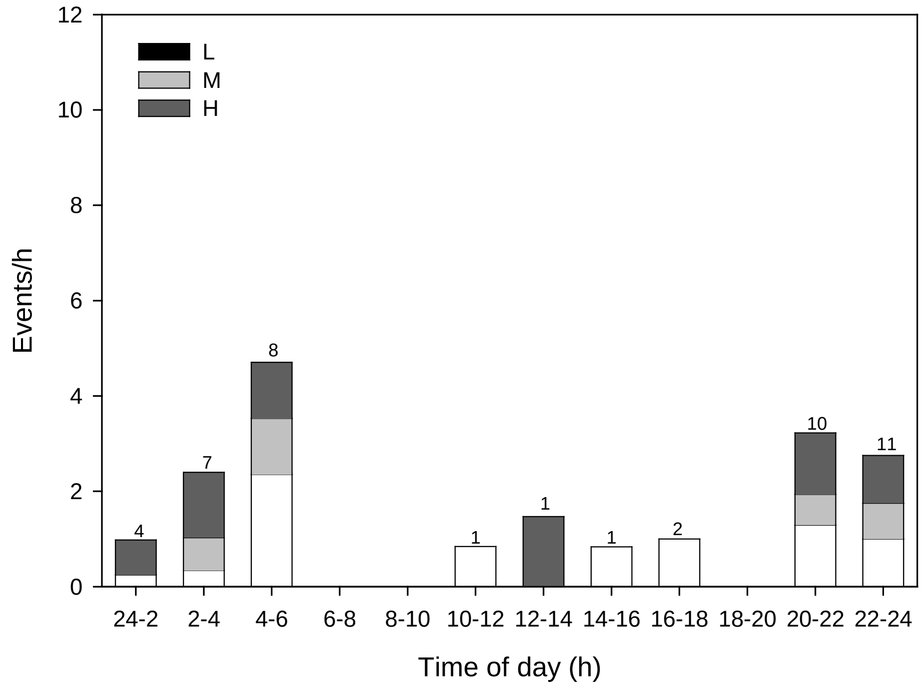

Figure 27. Number of events per hour by time of day at SDE during portrait DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

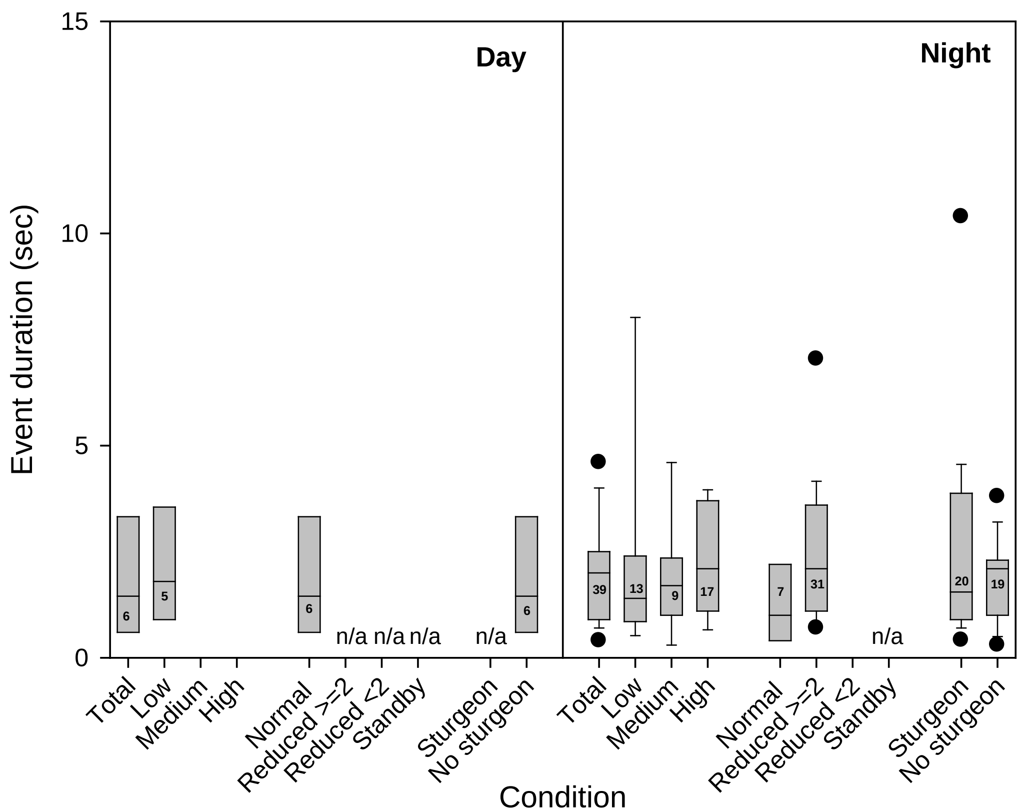

Figure 28. Duration of each lamprey event by day, night, velocity conditions, and presence or absence of sturgeon at SDE during portrait DIDSON deployment. Sample sizes are shown on each bar.

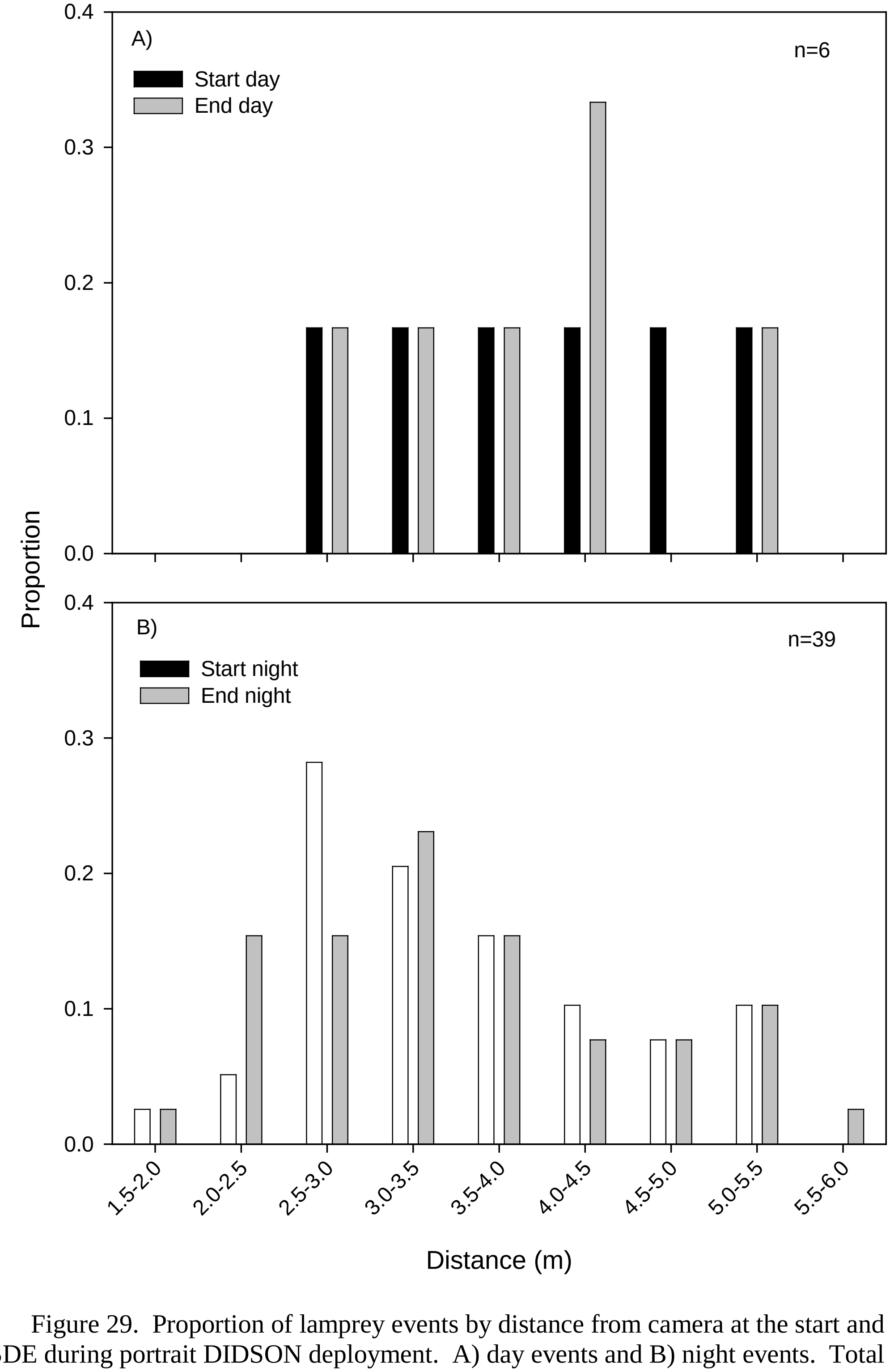

Figure 29. Proportion of lamprey events by distance from camera at the start and end of each event at SDE during portrait DIDSON deployment. A) day events and B) night events. Total Sample sizes are shown on each graph. The fishway wall was located between 1 and 4.5-6 m in the FOV. Note that the FOV was smaller closer to the camera.

North downstream entrance (NDE) landscape

Between 6 July and 15 July a total of 166 h of data were collected at the Washington–shore PH2 north downstream entrance (NDE) in landscape orientation and 30 hours of imagery (18% of total collected) were reviewed (Table 1; Appendix B Figure 3). Of the imagery reviewed 10.7 h was collected during the day (11% of total day imagery collected) and 19.3 h was collected at night (28% of total night imagery collected).

Event rate – Three hundred thirty-three lamprey events were documented (11.1 events/h). Fifty percent of the events were scored high confidence and less than 22% were scored low confidence (Table 2).

More lamprey observations (88%) occurred at night during normal operations (Figures 30-31) and a higher percentage of lamprey were classified with medium and high confidence at night (81%) (Figure 30). The number of events/h during the day was 3.9 (normal) and 3.0 (reduced>=2). Event rate at night was highest during reduced<2 (26.3) followed by normal operations (15.9). The number of lamprey events/h changed little with sturgeon present (Figure 30).

Net upstream movement – Net upstream movement was 24% at night and 25% during the day (Figure 32). Downstream movement was 73% at night and 64% during the day. Three percent of the night-time and 11% of daytime events were classified as no net movement. Net downstream movement at night during reduced<2 conditions was higher (86%) than during all other conditions (61-67%). Lamprey generally oriented (heading) upstream during the day regardless of the direction of movement and split between an upstream and downstream orientation at night (Figure 33).

Event duration – Median duration that lamprey were in the camera FOV was 1.8 s during the day and 1.3 s at night (Figure 34). Confidence of the target increased with duration. Lamprey classified with low confidence were in the FOV a median of 1.0 s (day) and 1.4 s (night). Those classified high confidence during the day were in the FOV a median of 4.6 s and at night a median of 1.4 s. There was little difference in duration of time in the FOV relative to velocity condition.

Lateral distribution – We observed a larger number of lamprey at mid ranges across the entrance compared to the inner and outer ranges, reflecting the camera FOV (Figure 35). Between 85-93% were between 2.5-5.0 m of the camera during the day and at night.

Prevalence of attachments – The proportion of fish observed attaching to a fishway structure was less than 1%. Two attachment events occurred at night during normal flow conditions (one lamprey attached to the wall and the other to the bulkhead slot).

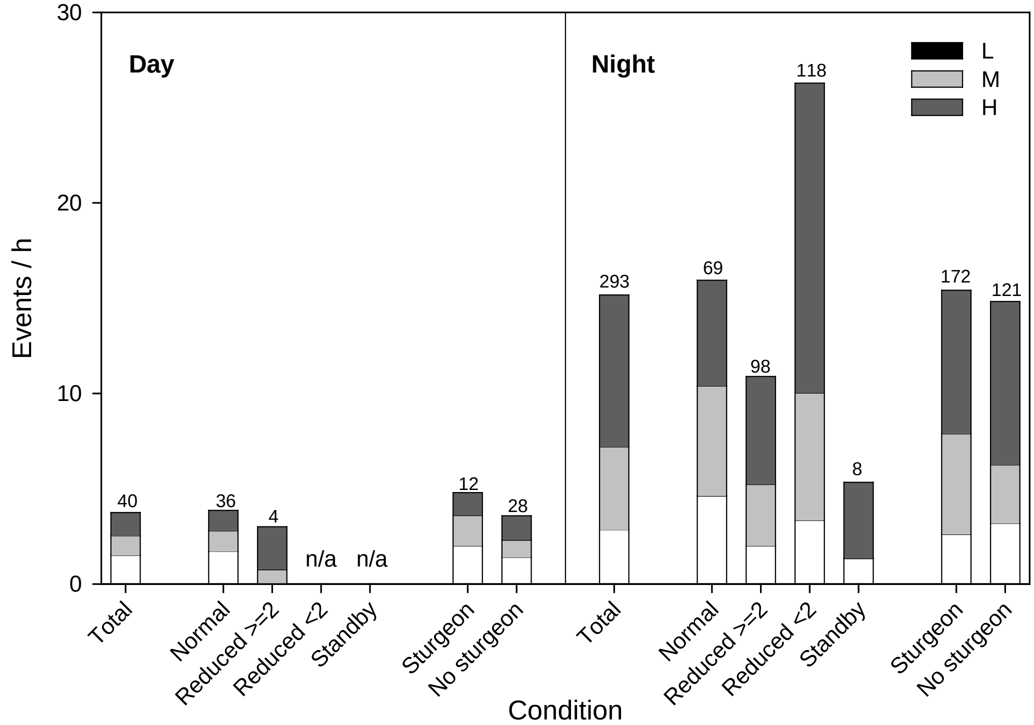

Figure 30. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at NDE during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

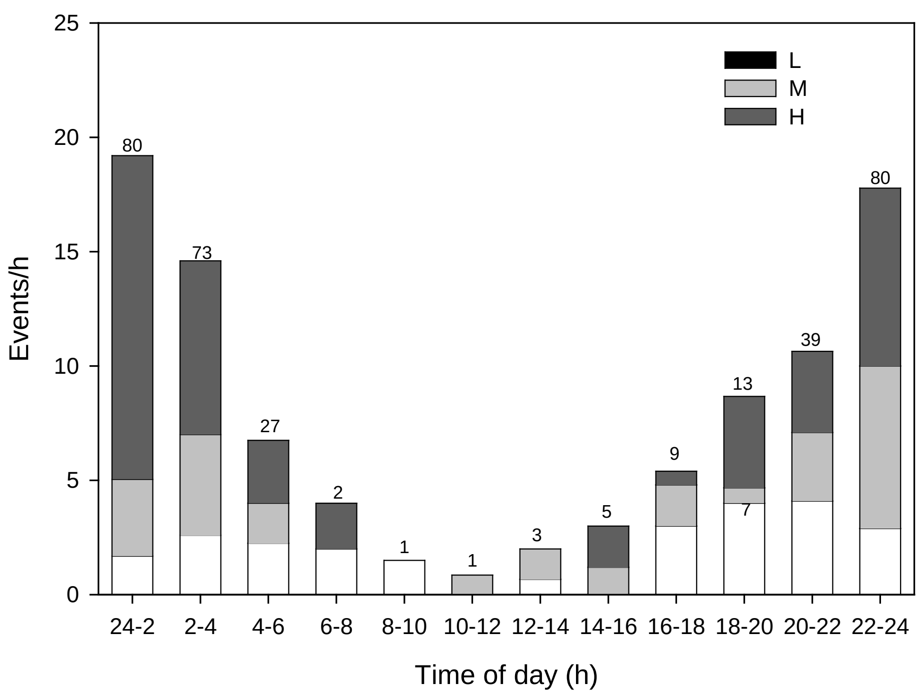

Figure 31. Number of events per hour by time of day at NDE during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

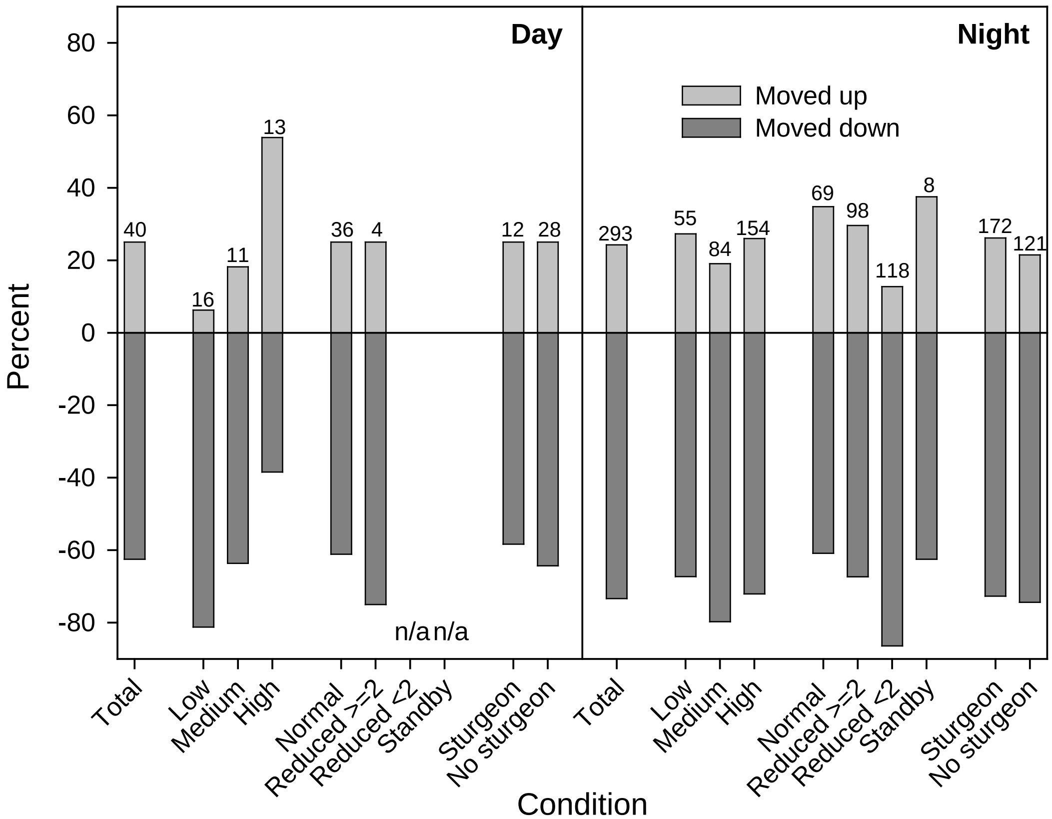

Figure 32. Percent of net movement upstream or downstream by day, night, velocity conditions, and presence or absence of sturgeon at NDE during landscape DIDSON deployment. Sample sizes are above each bar

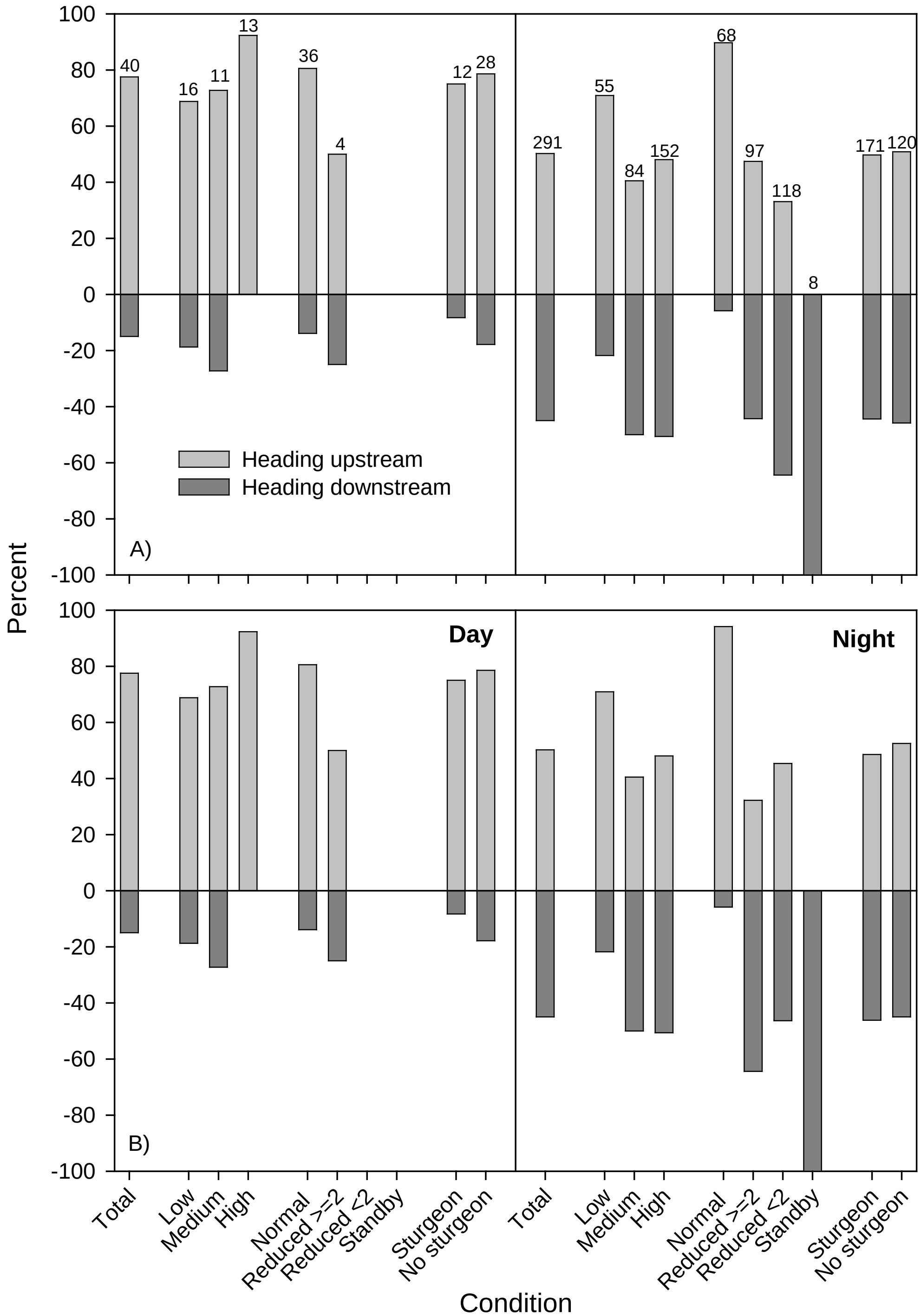

Figure 33. Percent of time a lamprey's orientation was upstream or downstream by day, night, velocity conditions, and presence or absence of sturgeon at NDE during landscape DIDSON deployment. Sample sizes are above each bar. Orientation in beginning of event A) and orientation at end of event B).

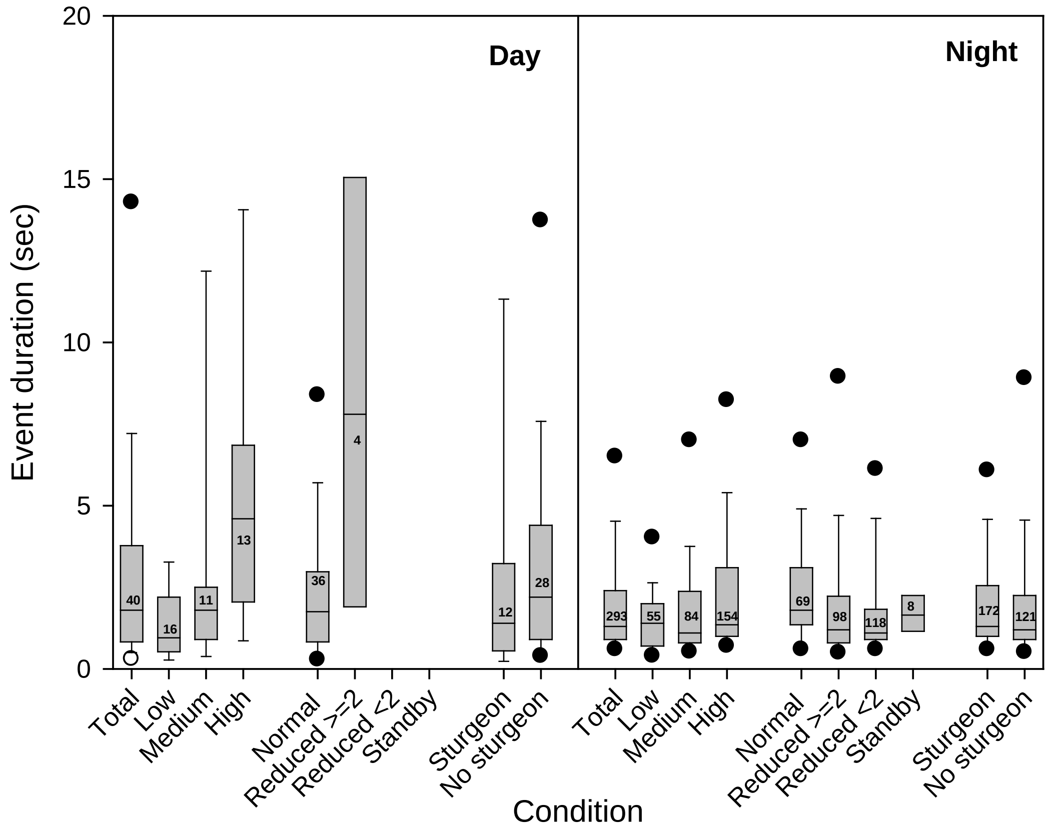

Figure 34. Duration of each lamprey event by day, night, velocity conditions, and presence or absence of sturgeon at NDE during landscape DIDSON deployment. Sample sizes are shown on each bar.

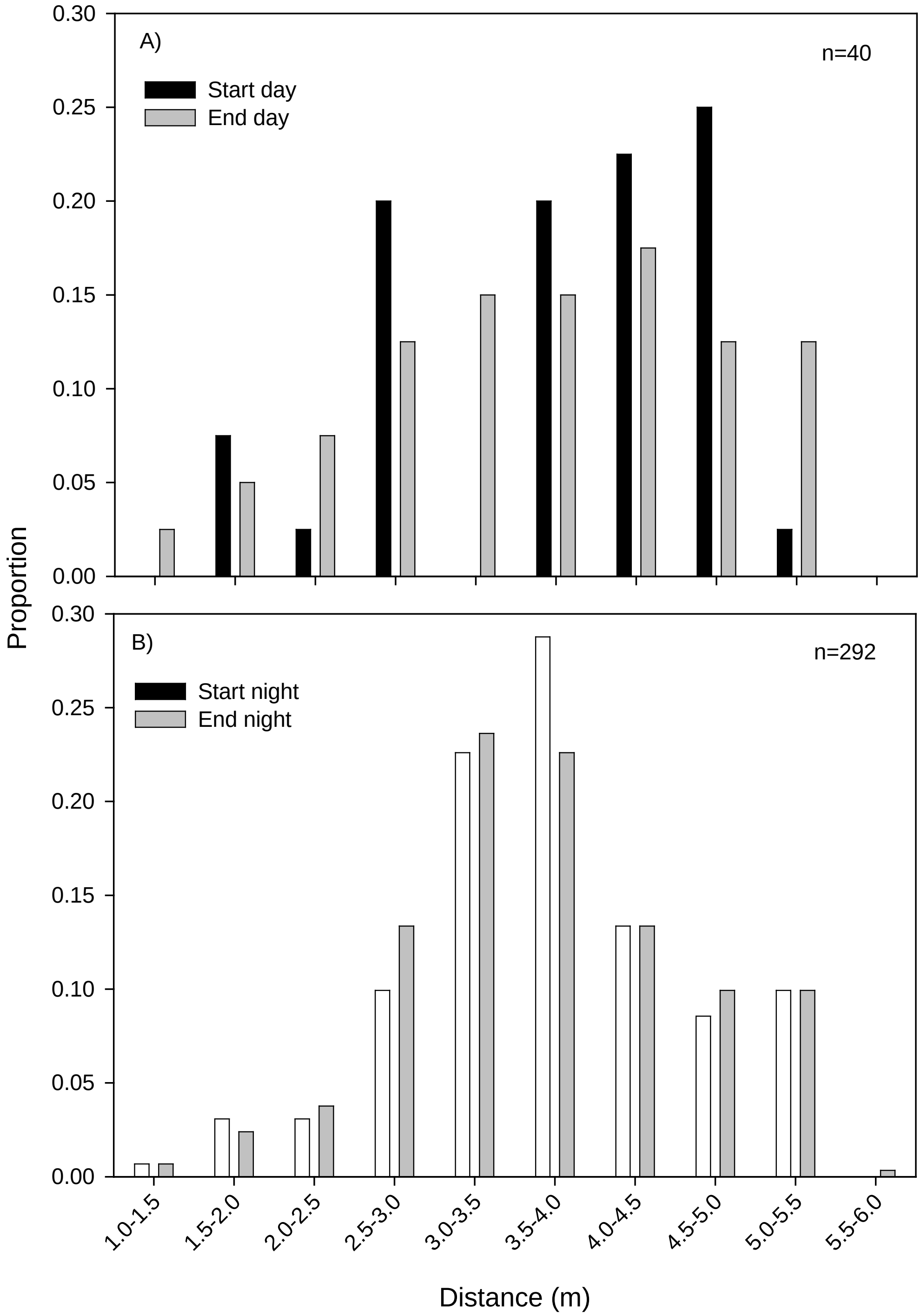

Figure 35. Proportion of lamprey events by distance from camera at the start and end of each event at NDE during landscape DIDSON deployment. A) day events and B) night events. Total Sample sizes are shown on each graph. The fishway wall was located between 1 and 5.5 m in the FOV. Note that the FOV was smaller closer to the camera.

North downstream entrance (NDE) portrait

Between 6 August and 17 August a total of 214 h of data was collected at the Washington–shore PH2 north downstream entrance (NDE) and 39 hours of imagery (18% of total collected) was reviewed (Table 1; Appendix B Figure 3). Of the imagery reviewed 11.8 h was collected during the day (9% of total day imagery collected) and 26.7 h was collected at night (31% of total night imagery collected).

Event rate by fishway operation and time of day – One hundred-forty lamprey events were documented (3.6 events/h). Thirty-two percent of the events were scored high confidence while 68% were scored low or medium confidence (Table 3).

Most lamprey (83%) were observed at night (Figures 36-37) with a higher percentage of lamprey classified as low confidence (45%) at night and during the day (Figure 36). The largest number of events were observed during normal operating conditions (6.3 events/h) and reduced >=2 (6.9 events/h). The number of lamprey events/h did not differ during the daytime with sturgeon present but was lower at night with sturgeon present (1.7 with sturgeon present and 6.1 with sturgeon absent) (Figure 36).

Event duration by location and time of day – Median duration of time lamprey were in the camera FOV was 1.5 s during the day and 1.7 s at night (Figure 38). Median duration for fish that attached was 68 s. Lamprey classified with low confidence were in the FOV 1.2 s (median day and night) and those classified high confidence were in the FOV with a median of 2.0 s (night) to 2.3 s (day). There was no difference in duration of time in the FOV relative to velocity condition.

Lateral distribution – We observed a larger number of lamprey in the far outer range across the entrance compared to the inner and middle ranges, reflecting the camera FOV (Figure 39). For those targets observed, between 60-67% were between 4.0-5.5 m of the camera.

Prevalence of attachments – The proportion of fish observed attaching to a fishway structure was 12% (n = 15) (Figure 40). Most attachments occurred at night (11 at night and 4 during the day) with the majority attaching to the wall.

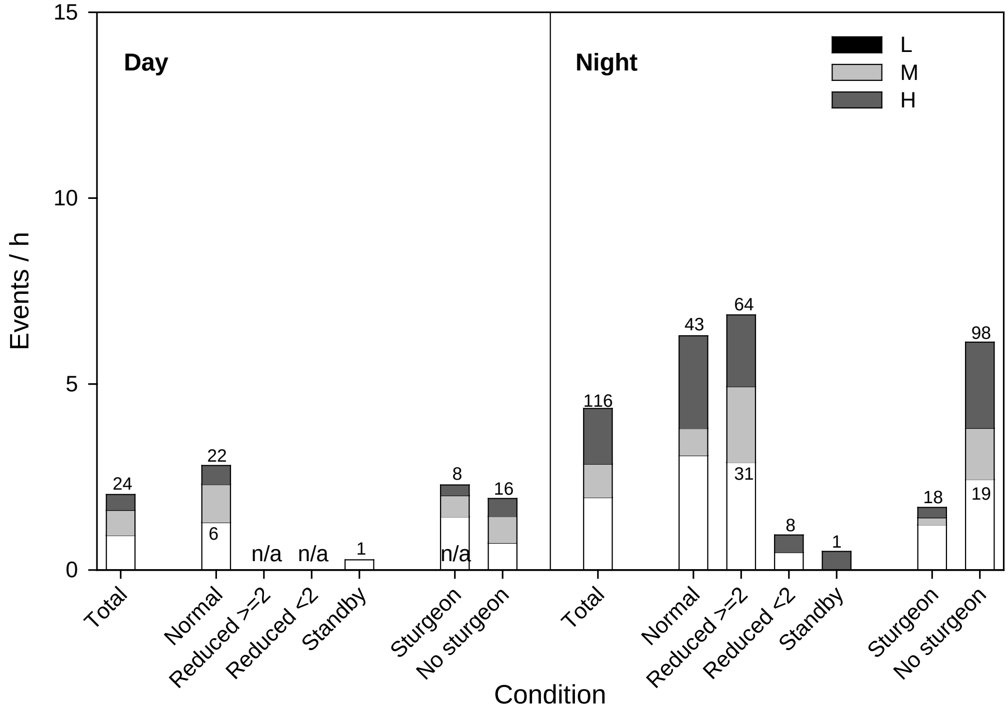

Figure 36. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at NDE during portrait DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

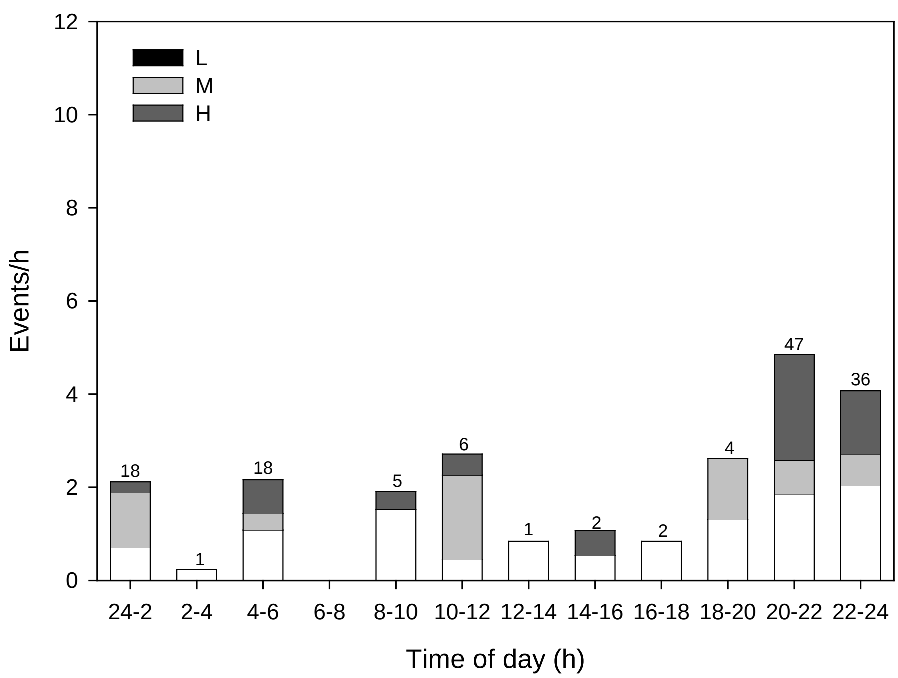

Figure 37. Number of events per hour by time of day at NDE during portrait DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

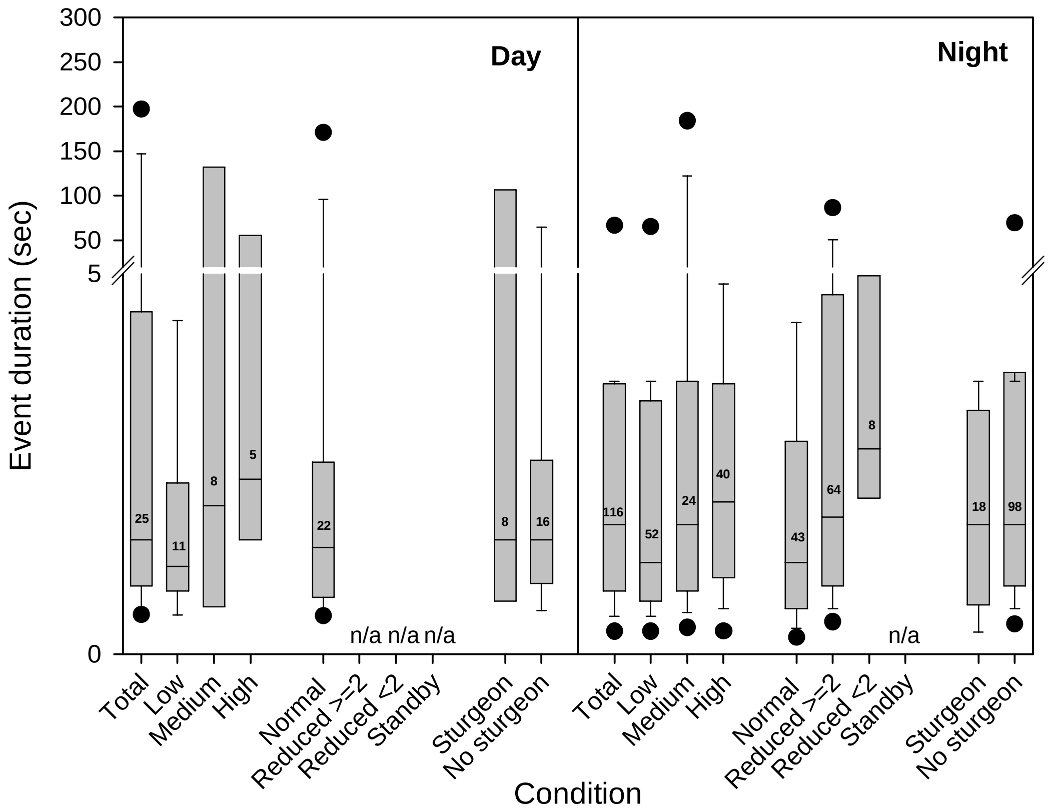

Figure 38. Duration of each lamprey event by day, night, velocity conditions, and presence or absence of sturgeon at NDE during portrait DIDSON deployment. Long durations shown for most of the upper quartiles are due to lamprey attachment. Sample sizes are shown on each bar.

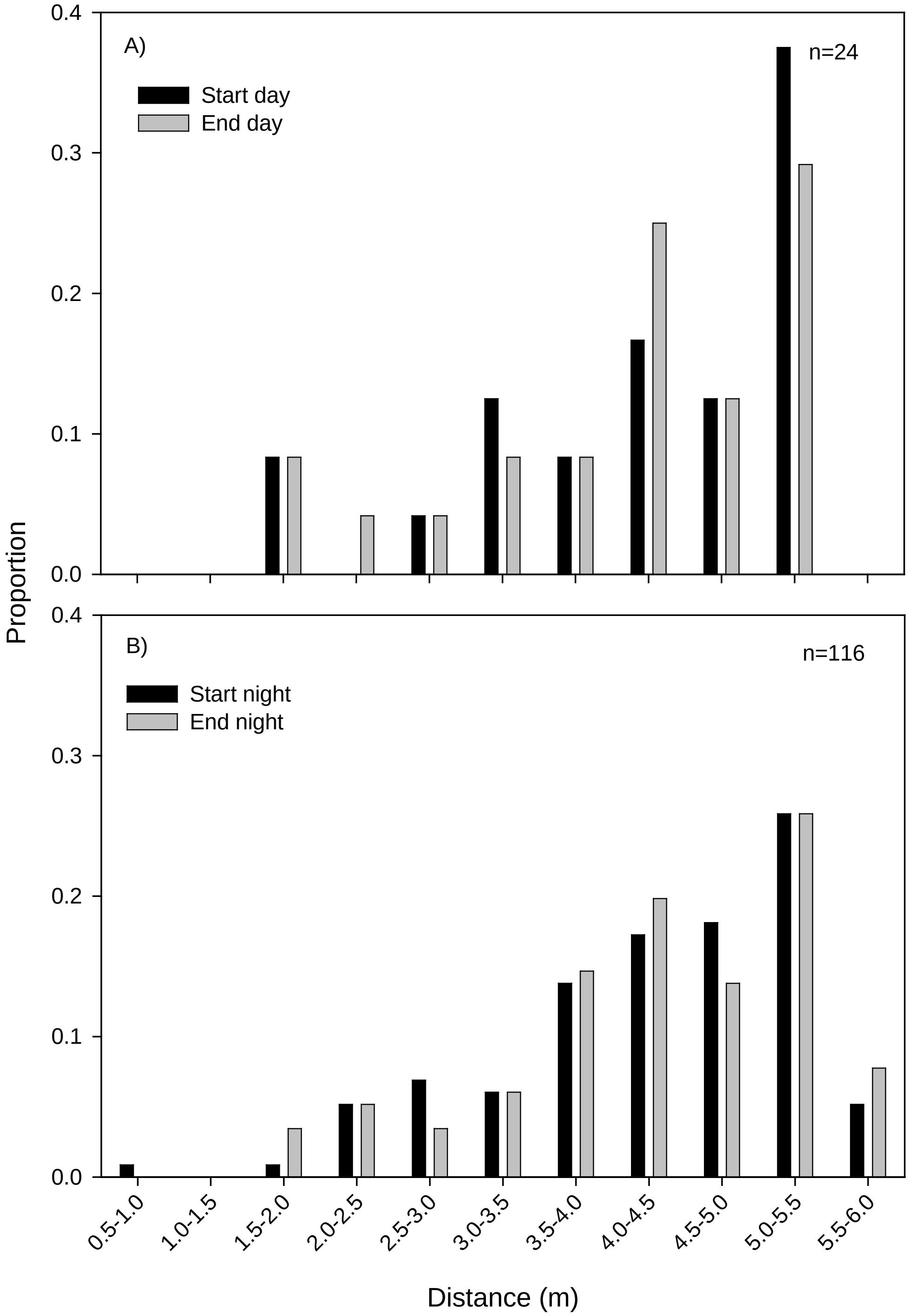

Figure 39. Proportion of lamprey events by distance from camera at the start and end of each event at NDE during portrait DIDSON deployment. A) day events and B) night events. Total Sample sizes are shown on each graph. The fishway wall was located between 2 and 5.5-6 m in the FOV. Note that the FOV was smaller closer to the camera.

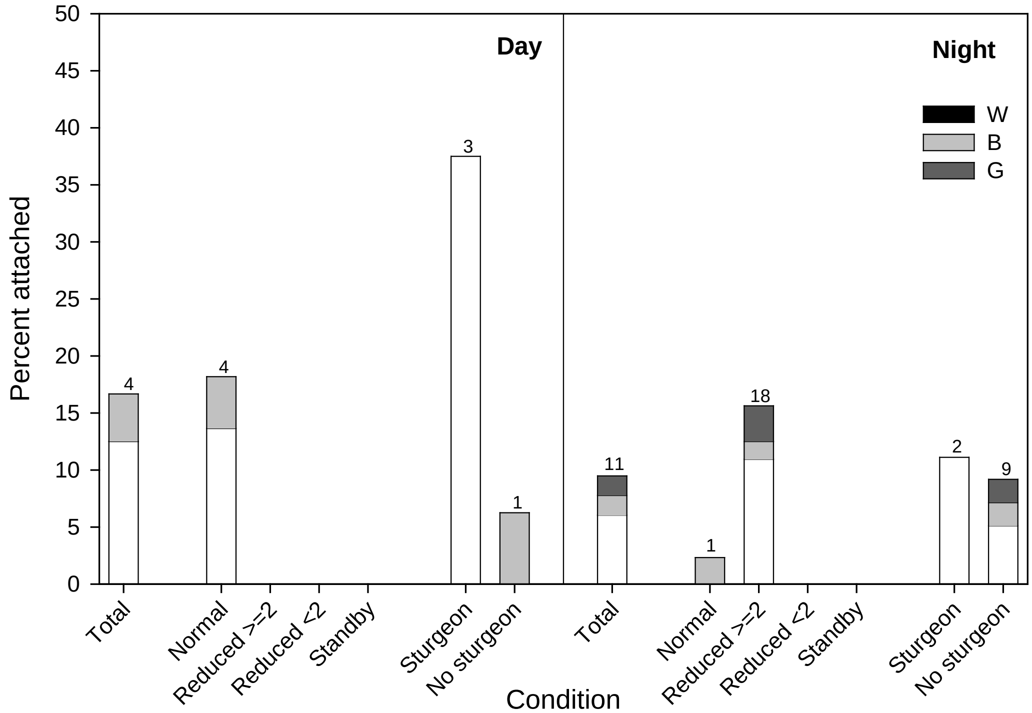

Figure 40. Percent of lamprey that attached by day, night, velocity conditions, and presence or absence of sturgeon at NDE during portrait DIDSON deployment. Bars are stacked by attachment location wall (W), bulkhead slot (B), and Gate (G). Sample sizes are shown on each bar.

North upstream entrance (NUE) landscape

Between 17-19 June a total of 28.8 h of data were collected at the Washington–shore PH2 north upstream entrance (NUE) in landscape orientation and 15.7 hours of imagery (55% of total collected) were reviewed (Table 1; Appendix B Figure 4). Of the imagery reviewed 4.0 h was collected during the day (34% of total day imagery collected) and 11.7 h was collected at night (69% of total night imagery collected). All imagery reviewed was collected using the auxiliary spreader lens (see Appendix A).

Event rate – One hundred-six lamprey events were documented with varying confidence (6.8 events/h). Thirty-one percent of the events were scored high confidence, 35% were scored medium confidence and 38% were scored low confidence (Table 2).

Most lamprey movements (84%) occurred at night (Figures 41-42). More lamprey were classified with medium and high confidence at night (69%) than during the day (41%) (Figure 41). During the day the largest proportion of events were observed during normal operating conditions (88%). At night the largest proportion of events (62%) occurred during reduced velocities. The event rate was the highest during reduced>=2 operations (12.2) and standby operations (13.1). Fewer lamprey were observed at night with sturgeon present (2.5 events/h with sturgeon and 16.5 per hour without sturgeon, Figure 41).

Net upstream movement –The majority of movement was upstream at night (64%). Movements up- and downstream were observed in approximately equal proportions during the day (Figure 43). Net upstream movement at night was similar with or without sturgeon present (66% with sturgeon and 58% without sturgeon). Sample size during the day was low (n < 20). Lamprey generally oriented (heading) upstream at night and split between an upstream and downstream heading during the day (Figure 44).

Event duration – Median duration that lamprey were in the camera FOV was 1.1 s during the day and 1.4 s at night (Figure 45). Confidence generally increased with duration. Targets classified with low confidence were in the camera FOV ranging from 1.2 s (median night) to 1.0 s (median day) and those classified as high confidence were in the FOV a median of 1.4 s (night) and 2.7 s (day).

Lateral distribution – Lamprey were in the first 5.5 m of the camera over 70% (daytime) and over 90% (nighttime) of the time (Figure 46).

Prevalence of attachments – We observed a single nighttime attachment event onto a fishway wall.

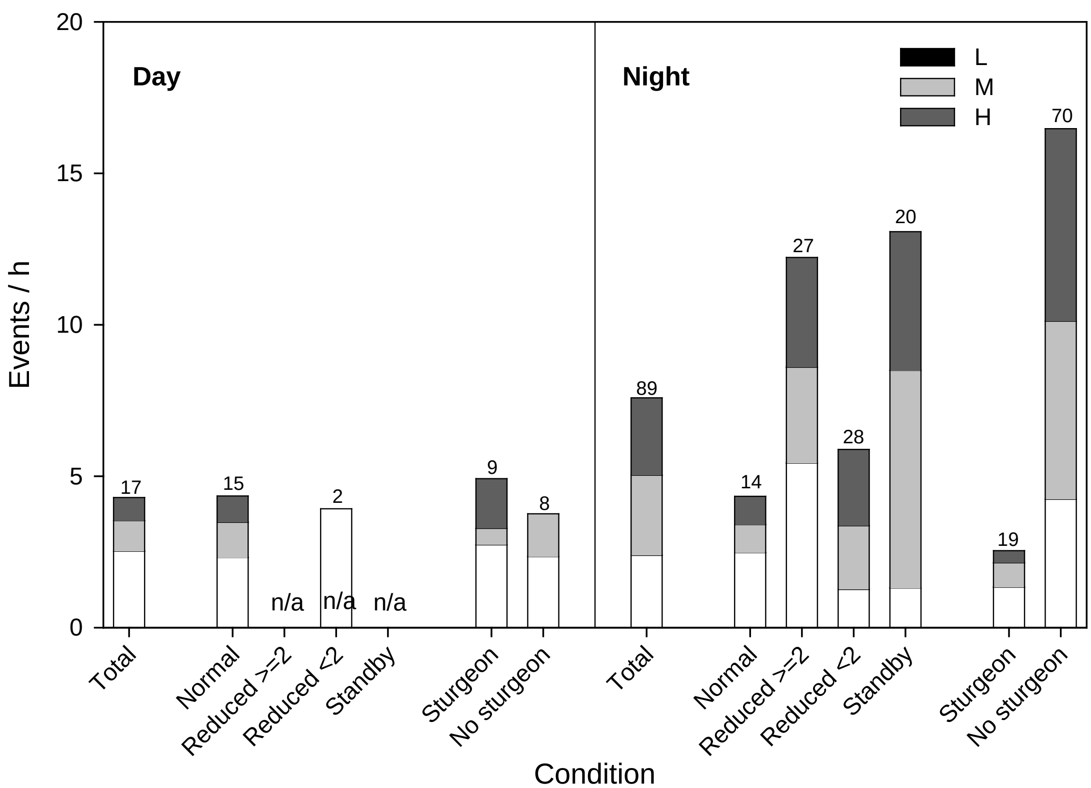

Figure 41. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at NUE during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

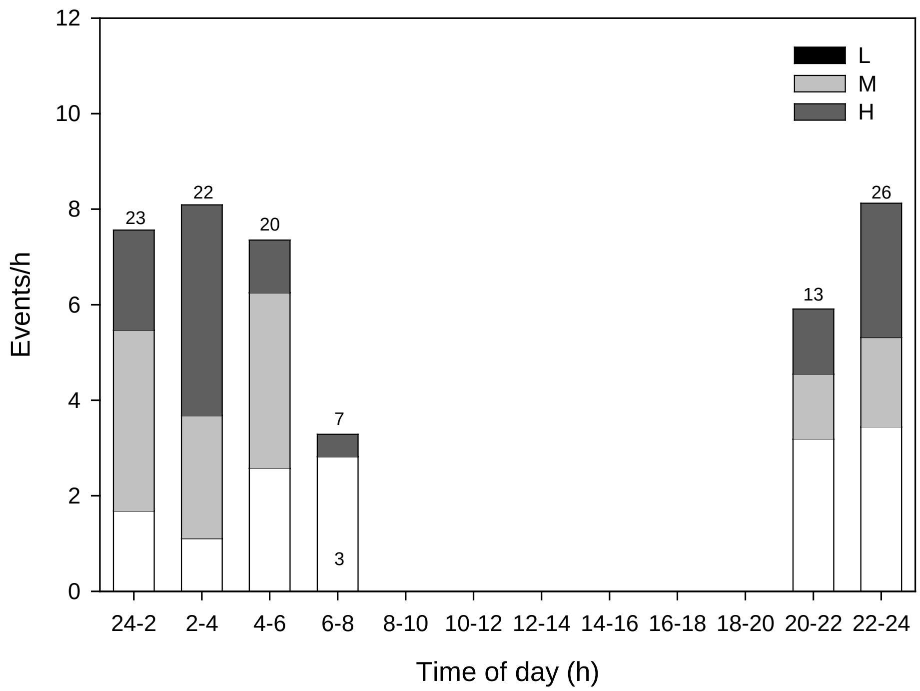

Figure 42. Number of events per hour by time of day at NUE during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

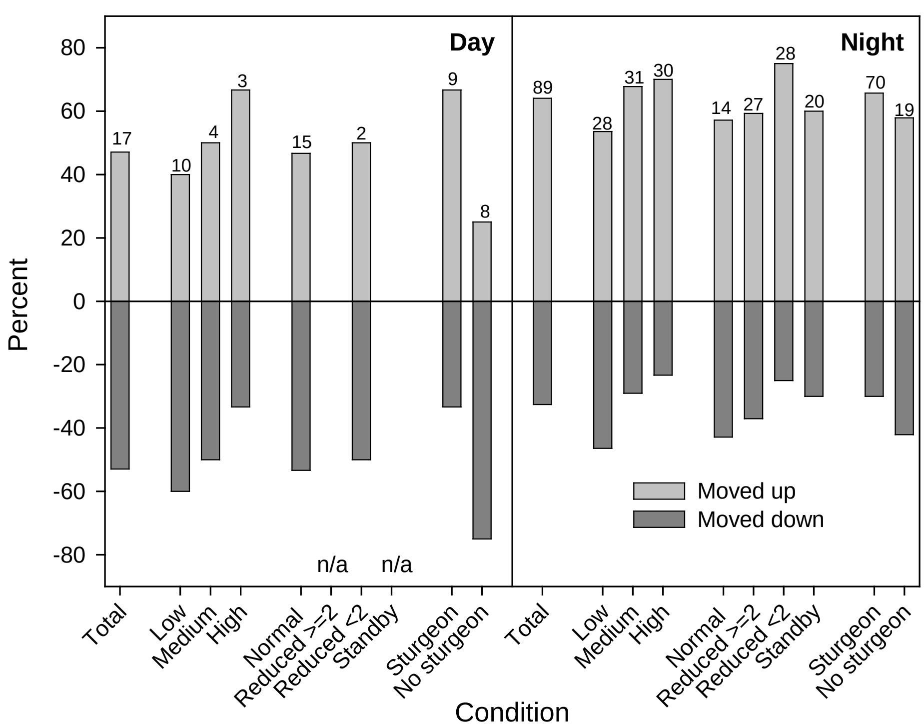

Figure 43. Percent of net movement upstream or downstream by day, night, velocity conditions and presence or absence of sturgeon at NUE during landscape DIDSON deployment. Sample sizes are above each bar.

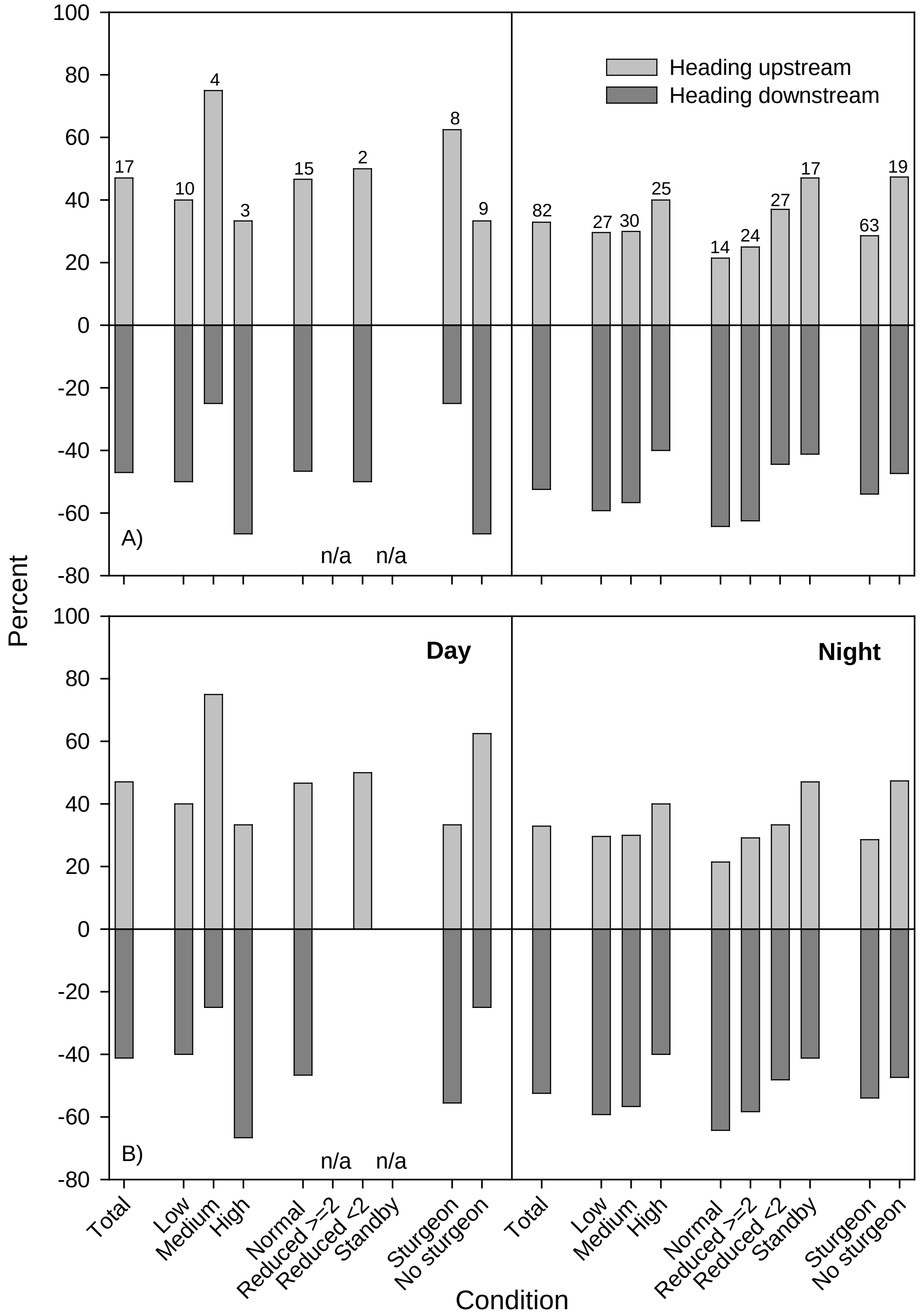

Figure 44. Percent of time a lamprey's orientation was upstream or downstream by day, night, velocity conditions, and presence or absence of sturgeon at NUE during landscape DIDSON deployment. Sample sizes are above each bar. Orientation in beginning of event A) and orientation at end of event B).

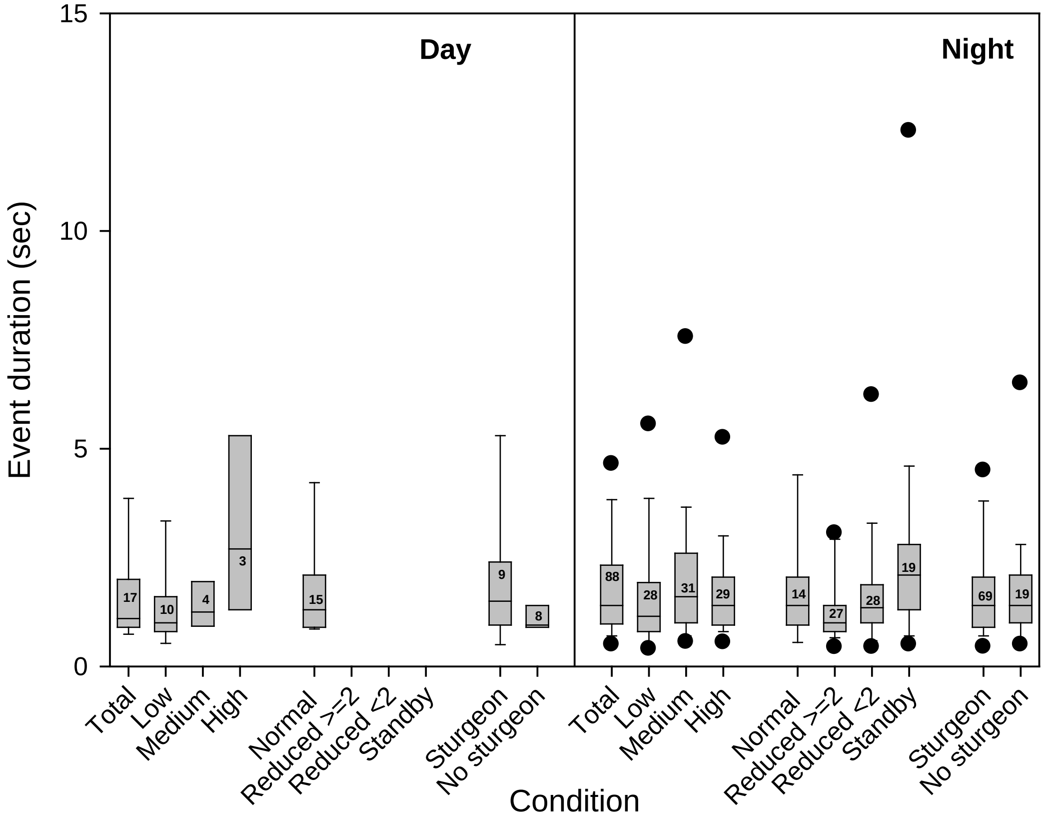

Figure 45. Duration of each lamprey event by day, night, velocity conditions, and presence or absence of sturgeon at NUE during landscape DIDSON deployment. Sample sizes are shown on each bar.

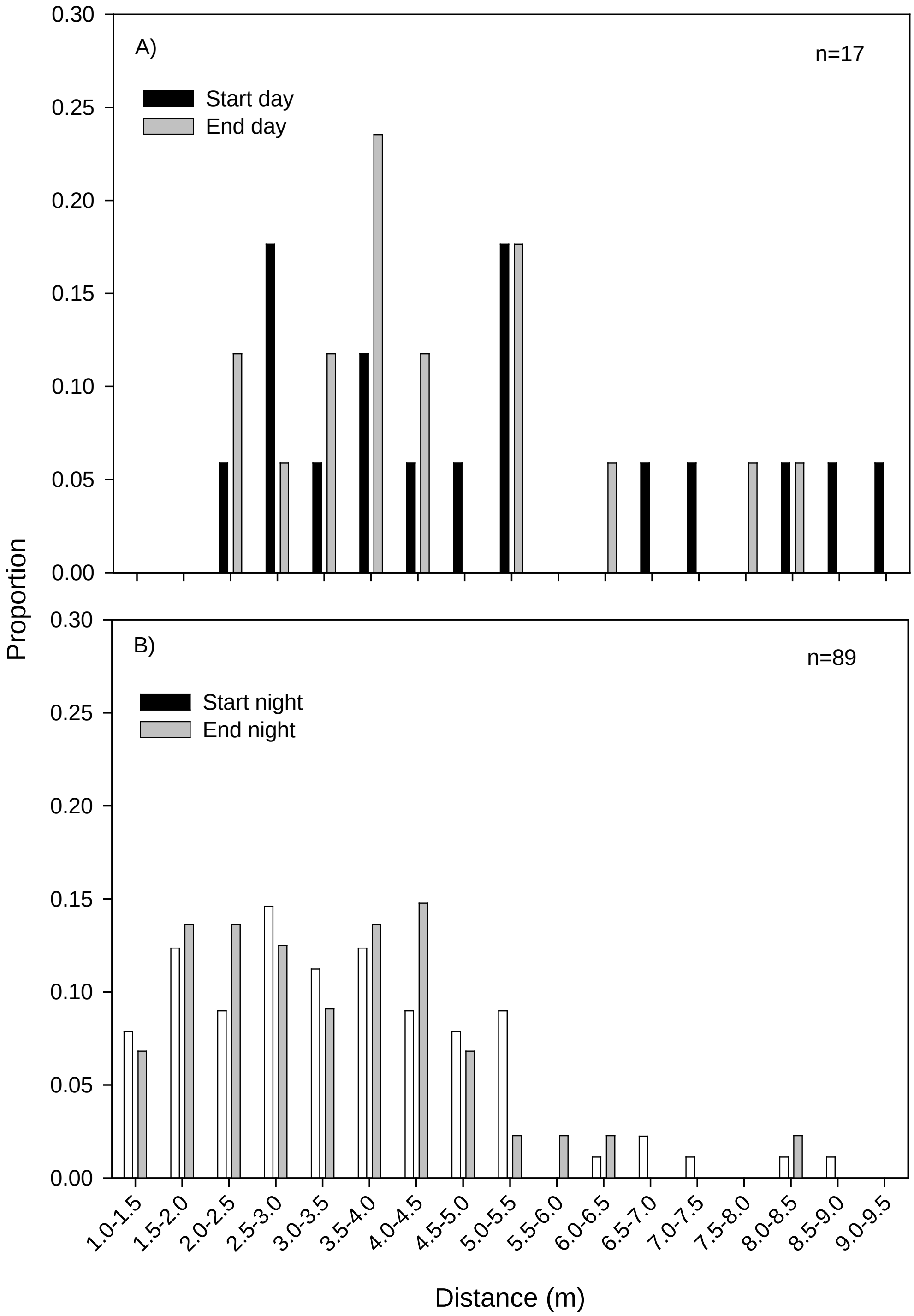

Figure 46. Proportion of lamprey events by distance from camera at the start and end of each event at NUE during landscape DIDSON deployment. A) day events and B) night events. Total Sample sizes are shown on each graph. Note that the FOV was smaller closer to the camera and the camera range varied between deployments (see Appendix Table 4).

Junction pool (JP) landscape

From 28 July- 6 August a total of 175 h of data were collected at the Washington–shore junction pool (JP) in landscape orientation (Table 1; Appendix B Figure 5). From 4-5 August the DIDSON was programmed at 20-min increments to a different horizontal tilt angle (these results are presented separately below). A total of 16.3 hours of imagery (9% of total collected) were reviewed. All fixed position (i.e., non-rotating) imagery was collected without the auxiliary spreader lens (see Appendix A).

Event rate – Thirty seven lamprey events were documented with varying confidence (2.3 events/h). Sixty- two percent of the events were scored high confidence, and 19% were scored medium and low confidence, respectively (Table 2).

Most lamprey movements (73%) occurred at night (Figures 47-48). Event rate was highest during normal operations (3.0 events/h) and slightly less but similar between the reduced >=2 and reduced<2 conditions at 2.0 and 2.2 events/h, respectively. Normal operating conditions predominated during the day. More lamprey were classified with medium and high confidence at night (85%) than during the day (70%, n = 10) (Figure 47). The number of events/h was lower with sturgeon present: 1.2 events/h with sturgeon and 8.7 events/h without sturgeon at night and 1.4 events/h with sturgeon and 4.0 events/h without sturgeon during the day (Figure 47).

Net upstream movement – Net upstream movement was 70% at night and 80% during the day (Figure 49). Upstream movement at night was higher without sturgeon present (81% compared to 55% with sturgeon present) but not during the day (100% upstream movement with sturgeon). No clear pattern emerged with respect to differences in confidence or swimming direction. Lamprey generally oriented (heading) upstream during the day and night regardless of the direction of movement (Figure 50).

Event duration – Median duration that lamprey were in the camera FOV was 2.4 s during the day and 2.4 s at night (Figure 51). Median time in the camera FOV was > 2 s for all confidence and velocity categories. Confidence improved slightly with duration at night.

Lateral distribution – Lamprey observations at night generally increased as distance from the camera increased out to 5.0-5.5 meters (pier nose). During the day most lamprey (80-90%) were observed between 2-4 m of the camera (Figure 52).

Prevalence of attachments – No attachments were observed in the junction pool.

Qualitative behavior – Past telemetry studies have observed a high rate of turn-around/passage failure in the PH2 Junction Pool and transition pool area. The floor of the fishway transitions from concrete in the collection channel to diffuser grating at the downstream end of the Junction Pool (this transition is visible in Appendix B Figure 5). We hypothesized that upwelling diffuser water confuses lamprey and induces downstream movement to the collection channel and tailrace. As an observational test of this hypothesis, we examined adult lamprey behavior at the transition and found no instances of altered swimming behavior above the diffuser grating or any turnaround events at this location. We note the spatial extent of monitoring was limited to the narrow sample volume at the beginning of the junction pool and hydraulic effects of diffuser water may affect lampreys as hypothesized up- or downstream of the monitored location.

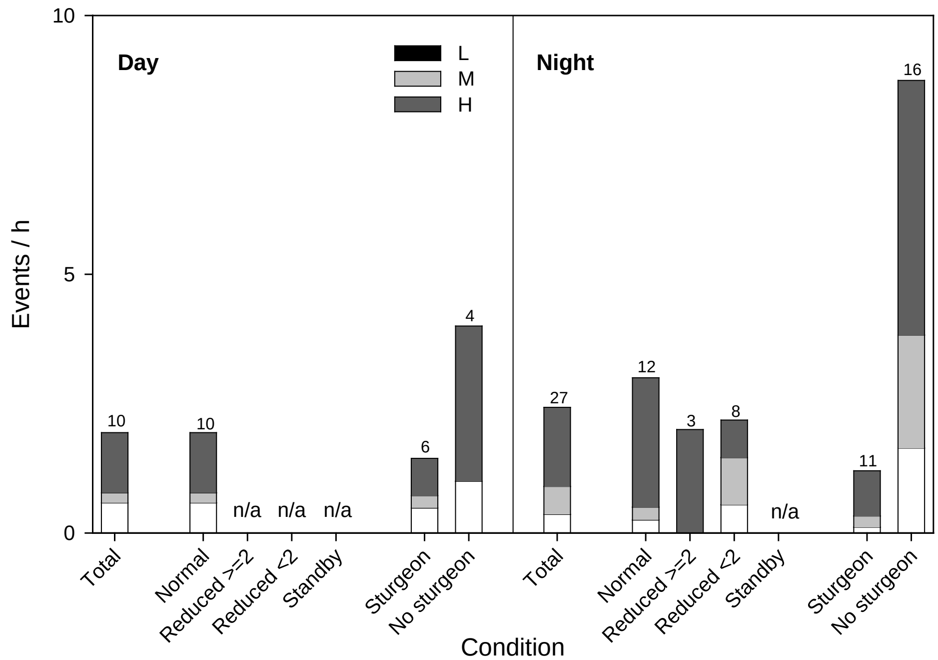

Figure 47. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at JP during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

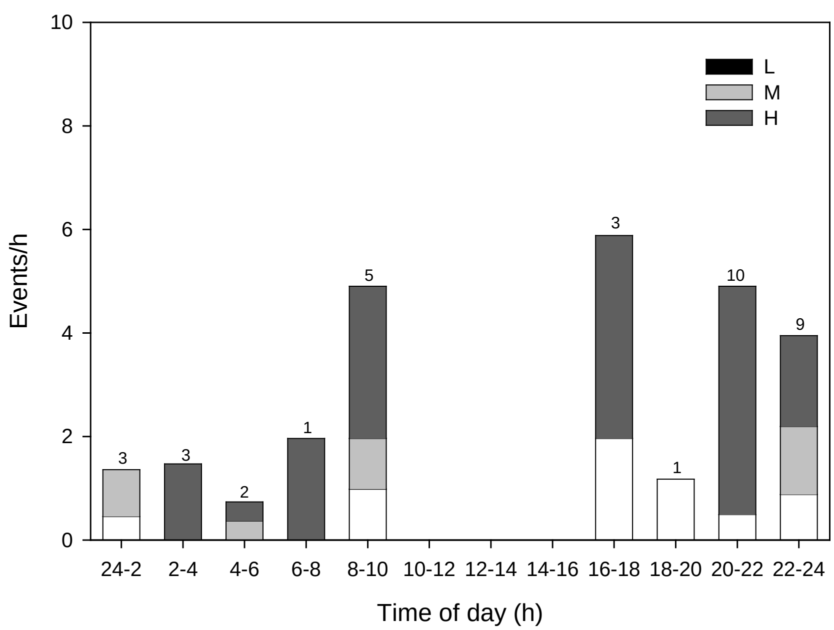

Figure 48. Number of events per hour by time of day at JP during landscape DIDSON deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

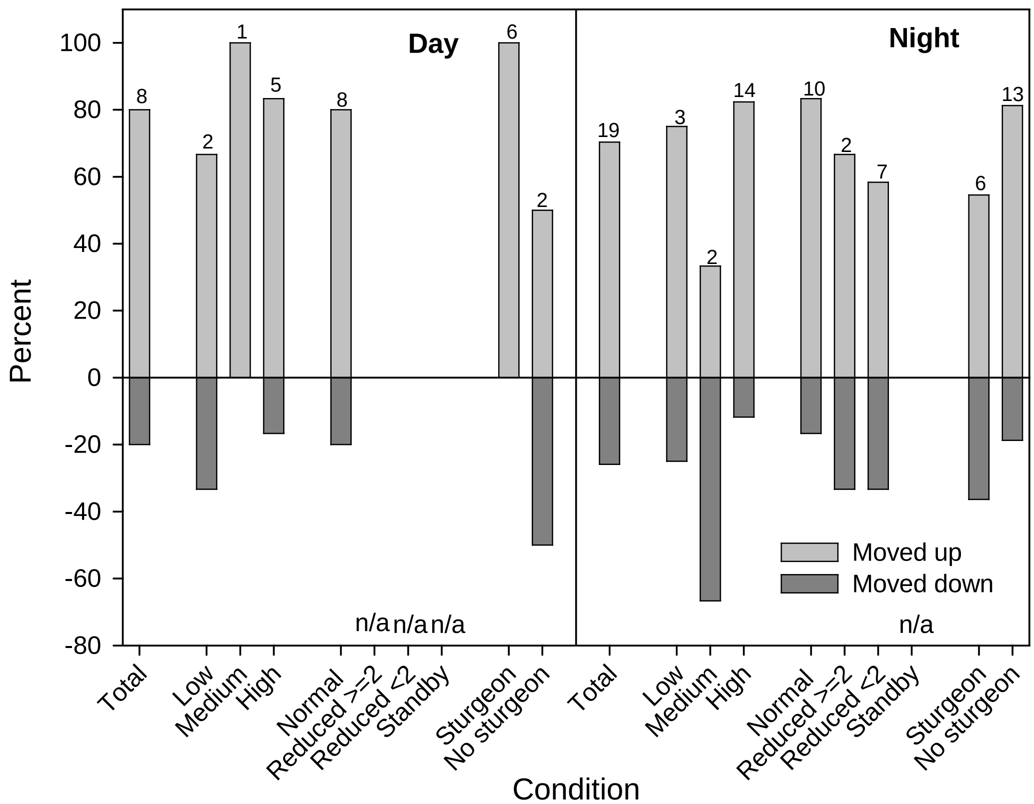

Figure 49. Percent of net movement upstream or downstream by day, night, velocity conditions and presence or absence of sturgeon at JP during landscape DIDSON deployment. Sample sizes are above each bar.

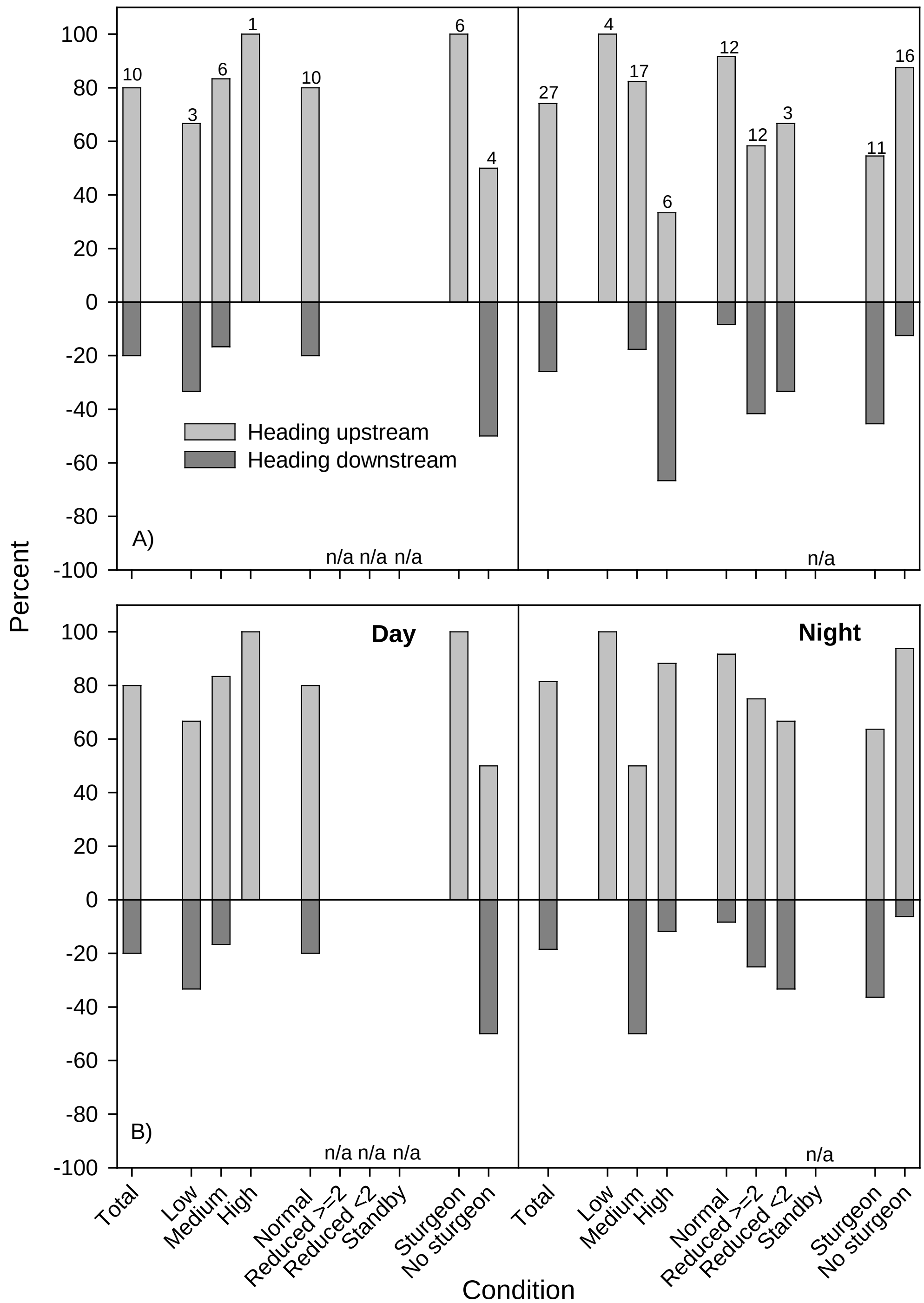

Figure 50. Percent of time a lamprey's orientation was upstream or downstream by day, night, velocity conditions, and presence or absence of sturgeon at JP during landscape DIDSON deployment. Sample sizes are above each bar. Orientation in beginning of event A) and orientation at end of event B).

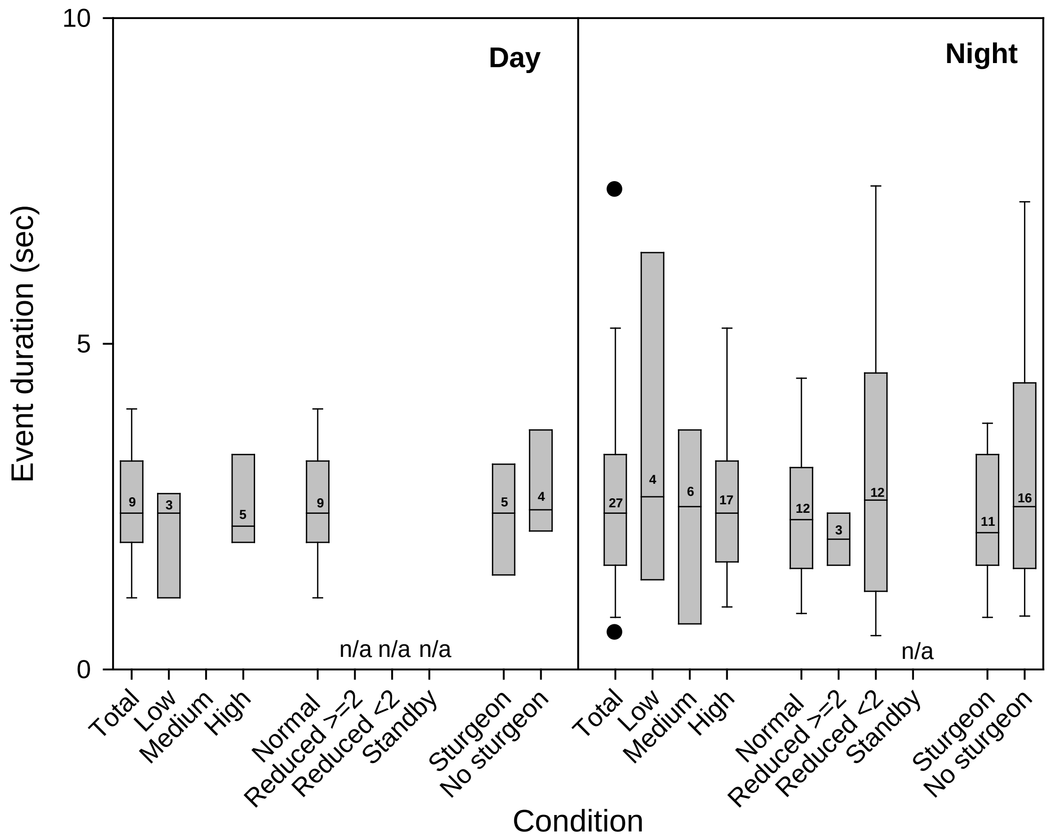

Figure 51. Duration of each lamprey event by day, night, velocity conditions, and presence or absence of sturgeon at JP during landscape DIDSON deployment. Sample sizes are shown on each bar.

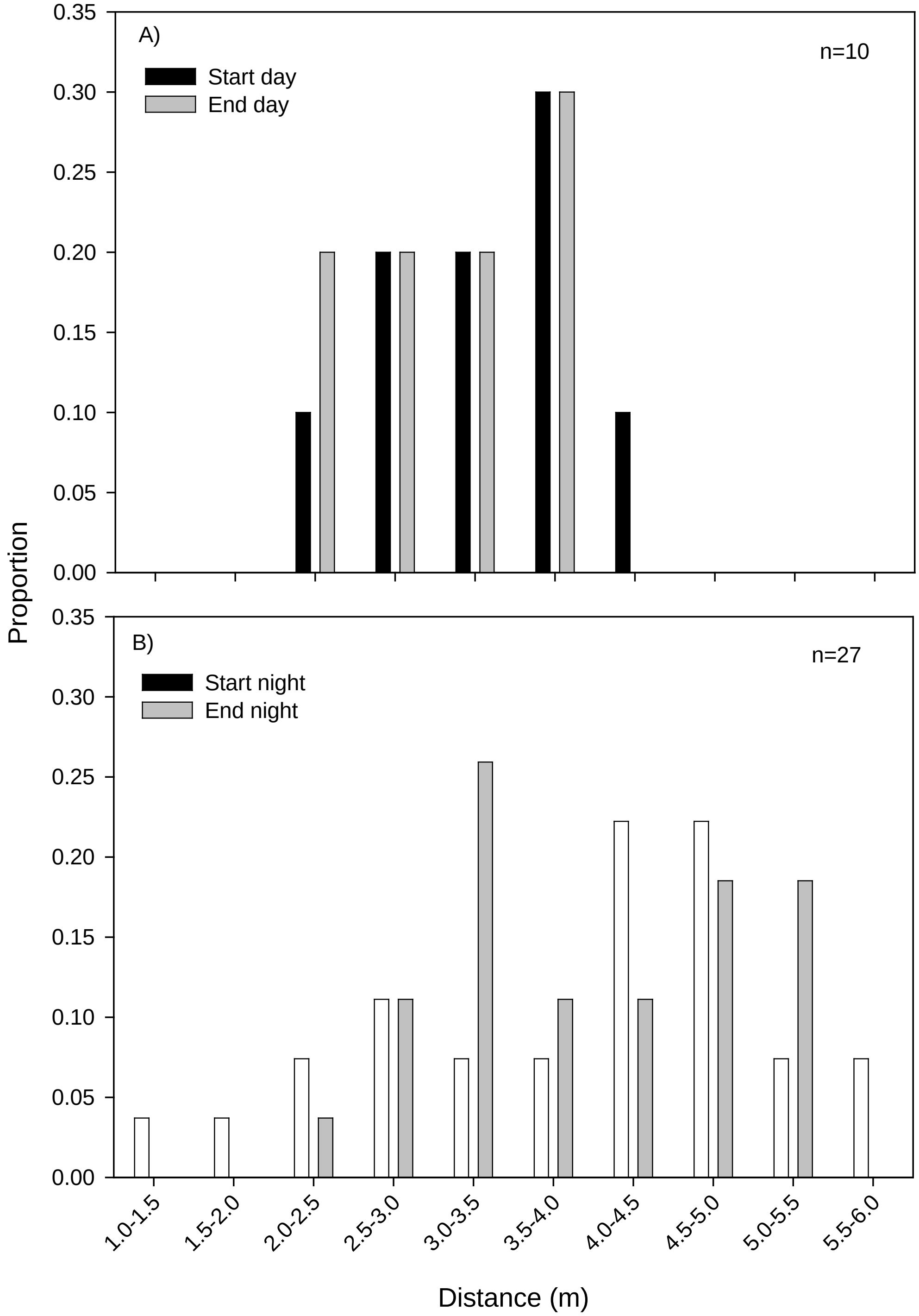

Figure 52. Proportion of lamprey events by distance from camera at the start and end of each event at JP during landscape DIDSON deployment. A) day events and B) night events. Total Sample sizes are shown on each graph. Note that the FOV was smaller closer to the camera.

Junction pool tilting camera experiment and associations with sturgeon

Lamprey were observed at different rates in three JP camera angle treatments during both the day and night (Figure 53). In the daytime experiment, 12.5 events/h were observed when the camera was in a nearly horizontal deployment, versus 6.5 events/h when oriented towards the fishway floor and 3.5 events/h near the water surface. In the night-time experiment, 26.5 events/h were observed when the camera was nearly horizontal, versus 5.5 events/h when oriented closer to the fishway floor and 16.0 events/h near the water surface.

The increased density of lamprey in mid-water and upper-water sample volumes was inversely related to sturgeon activity. During the day, the mean sturgeon index was 7.4 near the fishway bottom, 0.2 in the middle deployment, and 0.1 near the fishway surface (Figure 54). At night, the sturgeon index values were 25.5 (bottom), 8.8 (middle), and 5.3 (near surface).

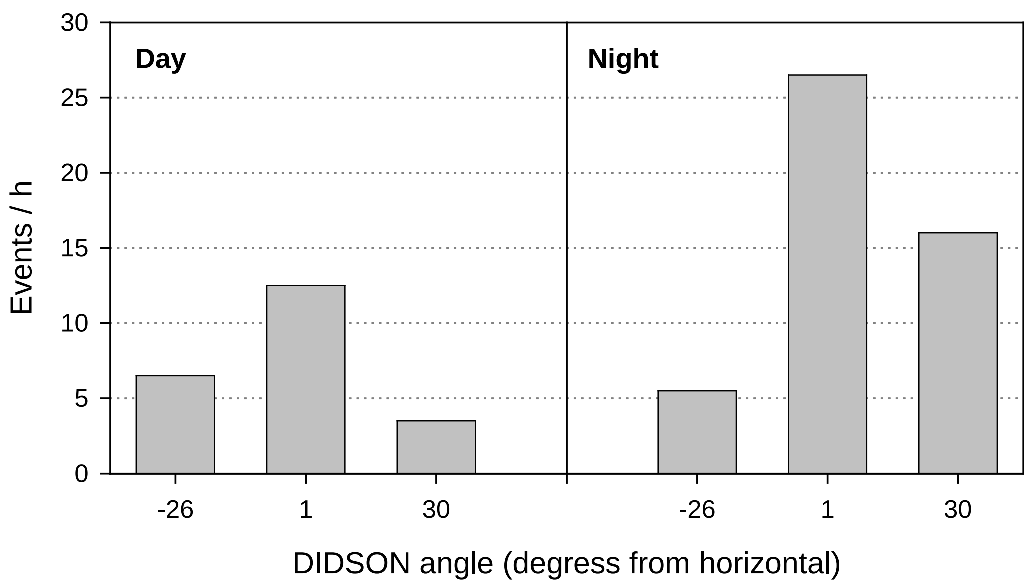

Figure 53. Numbers of lamprey events / h recorded in the junction pool (JP) during the tilting DIDSON experiment. The DIDSON automatically changed tilt angle every 20 minutes within two 6 h blocks (1 day, 1 night).

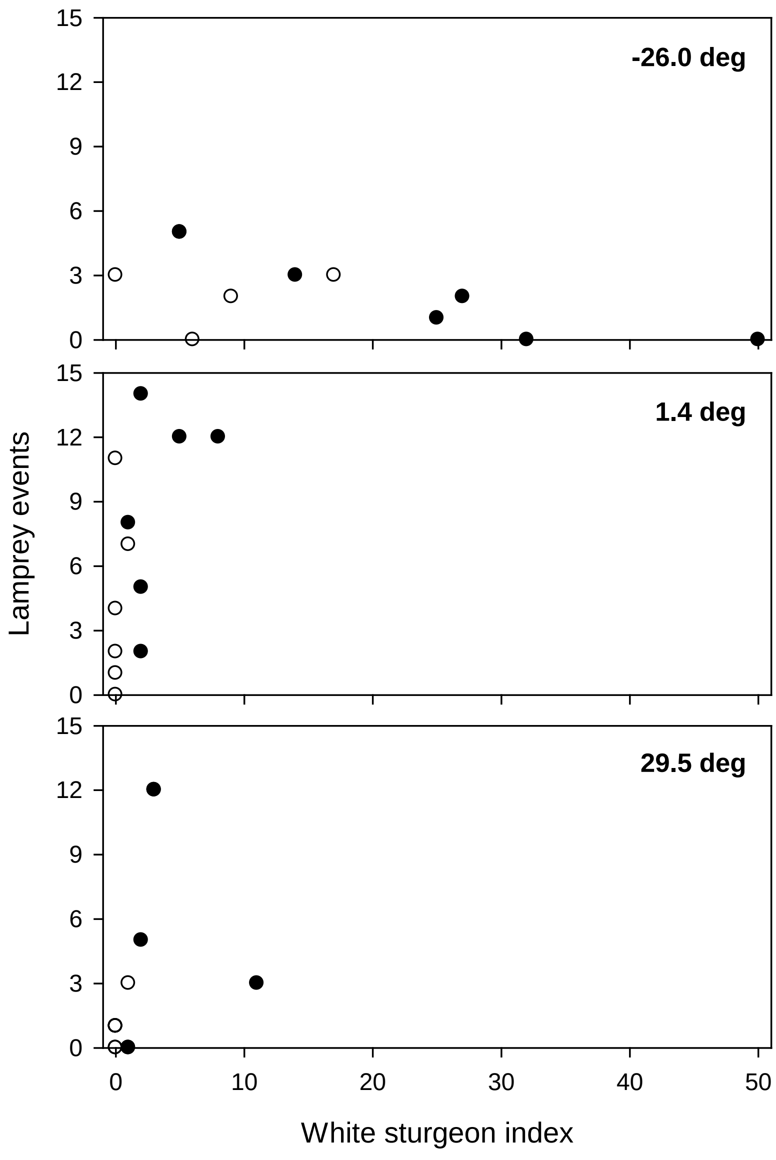

Figure 54. Scatterplots that show the relationship between the number of lamprey events observed and an index of white sturgeon presence in the junction pool (JP) at three different DIDSON tilt angles. Each point represents a single 20 min observation period in the experiment, with black symbols (●) for nighttime files and open symbols (○) for daytime files. The sturgeon index was the number of sturgeon observed in ~50 DIDSON frames per file, randomly selected at approximately 30 sec intervals.

Junction pool (JP) dual stacked cameras (landscape and portrait)

From 18 – 21 August both cameras were mounted on a trolley in the horizontal (landscape) and vertical (portrait) orientations (stacked camera deployment) in an effort to collect simultaneously information on fish depth (within the sample volume) and the direction of movement relative to flow (Appendix B Figure 6). The auxiliary spreader lens was not used. Of the 4.3 h of landscape and portrait video watched we observed three times as many lamprey events collected with the camera in the landscape position (Figures 55-56). Lamprey were scored with higher confidence with the camera in the landscape position (68% scored as medium or high confidence compared to 32% in the portrait position). The duration of time fish were in the cameras FOV was 2.9 s (median landscape) and 2.3 s (median portrait). With both configurations lamprey were detected out to 11.5 m although resolution was poor relative to single camera deployments as a result of interference from simultaneous acoustic signal returns.

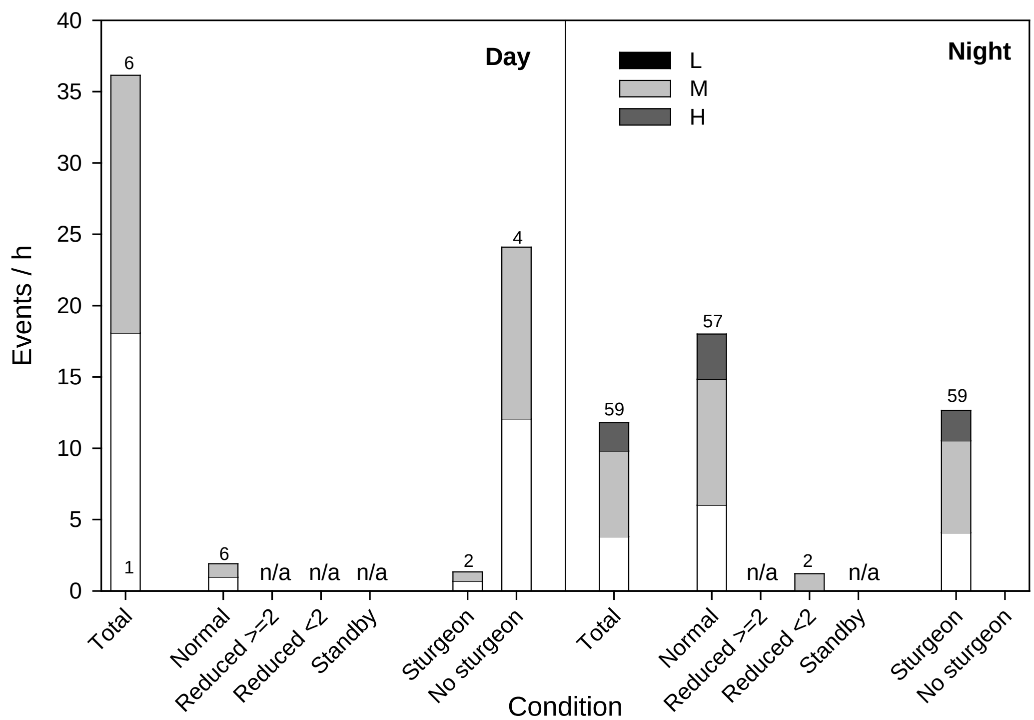

Figure 55. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at JP during landscape DIDSON stacked deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

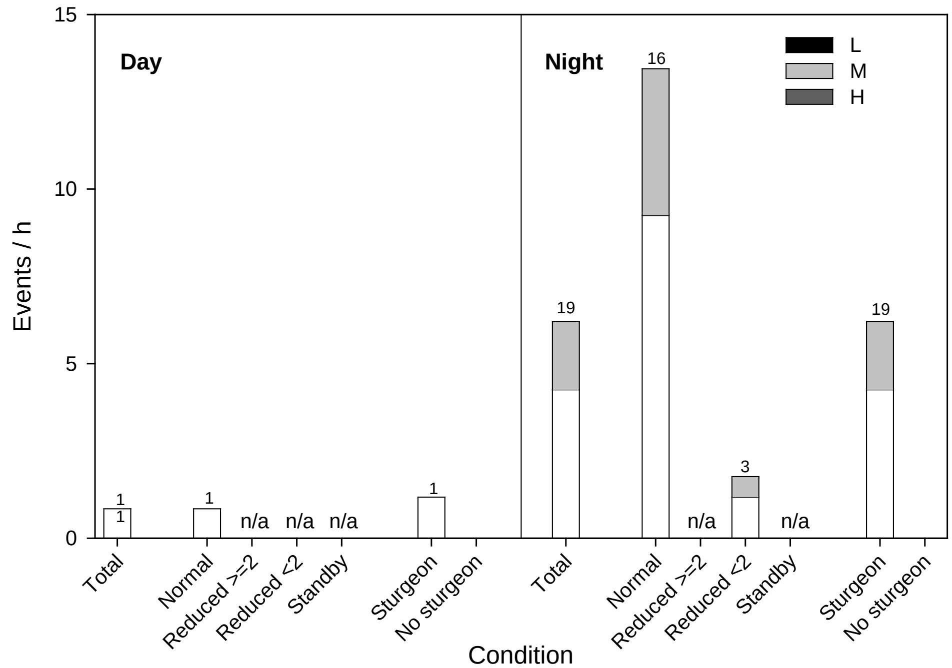

Figure 56. Number of events per hour by day, night, velocity conditions, and presence or absence of sturgeon at JP during portrait DIDSON stacked deployment. Bars are stacked by confidence level of low (L), medium (M), and high (H). Sample sizes are above each bar.

Portrait mode lamprey depth data

We estimated lamprey depth for 256 lamprey events scored in portrait mode at NDE, SDE, and SUE. This was 43% of all scored portrait mode events at these sites. In all cases, lamprey were distributed through most of the field of view at the time of first detection and mean depths reported below largely reflect the mean sample volume rather than the true distribution of lamprey.

At NDE, mean lamprey depth was 3.5 m when the DIDSON was located 2.6 m below the surface and oriented at 10° below horizontal (Figure 57). The mean was 2.5 m when the camera was 1.8 m below the surface. In both NDE deployments, lamprey were slightly shallower (0.2-0.7 m, on average) during reduced velocity than during normal operations.

At SDE, mean lamprey depths were 3.5 and 2.8 m when the DIDSON was 1.3 and 0.3 m below the surface, respectively (Figure 58). At this site, the DIDSON was tilted 31° below horizontal. Lamprey were 0.2 m shallower, on average, during the reduced velocity condition in one deployment and were neither deeper nor shallower in the second deployment. Note that there were relatively few events scored during the normal operation at this site, limiting the comparison.

At SUE, mean lamprey depths were 3.8 and 2.6 m when the DIDSON was 1.8 and 1.0 m below the surface, respectively (Figure 59). At this site, the DIDSON was tilted 30° below horizontal. Lamprey were 0.9 m shallower, on average, during the reduced velocity condition in one deployment and were 0.5 m deeper during reduced velocity in the second deployment.

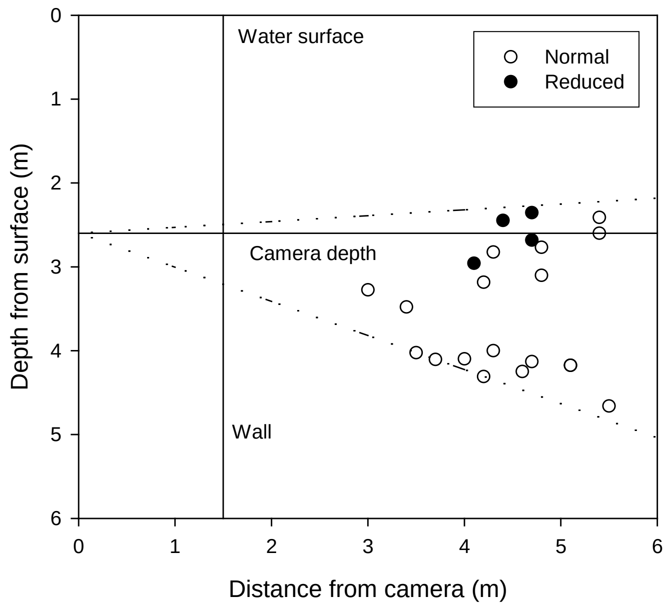

Figure 57. Locations where lamprey were first detected in the portrait mode deployment at NDE on 6-7 August (left panel) and 9-17 August (right panel), looking downstream. Dashed lines represent the DIDSON field of view. The fishway walls were located at approximately 1.5 m (south wall) and 6 m (north wall). Solid circles (●) show events scored during reduced fishway velocity operations and open circles (○) show events scored during normal operations. Note different camera depths.

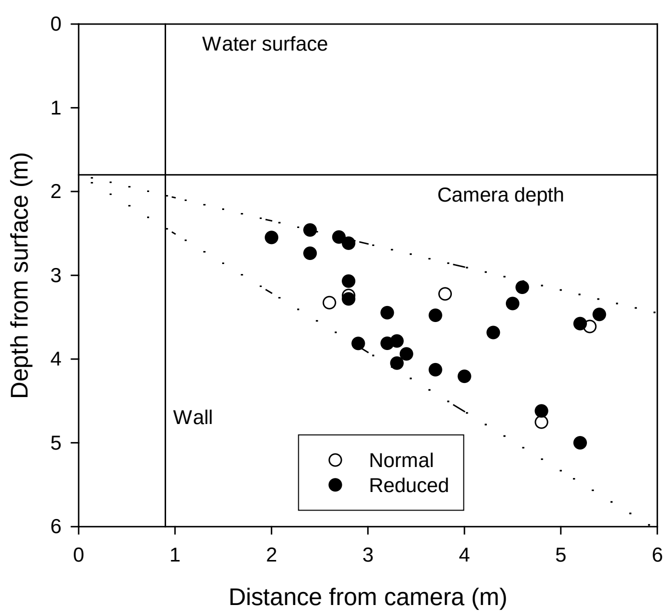

Figure 58. Locations where lamprey were first detected in the portrait mode deployment at SDE on 31 August-1 September (left panel) and 2 September (right panel). Dashed lines represent the DIDSON field of view. The fishway walls were located at approximately 0.9 m and 6 m. Solid circles (●) show events scored during reduced fishway velocity operations and open circles (○) show events scored during normal operations. Note different camera depths.

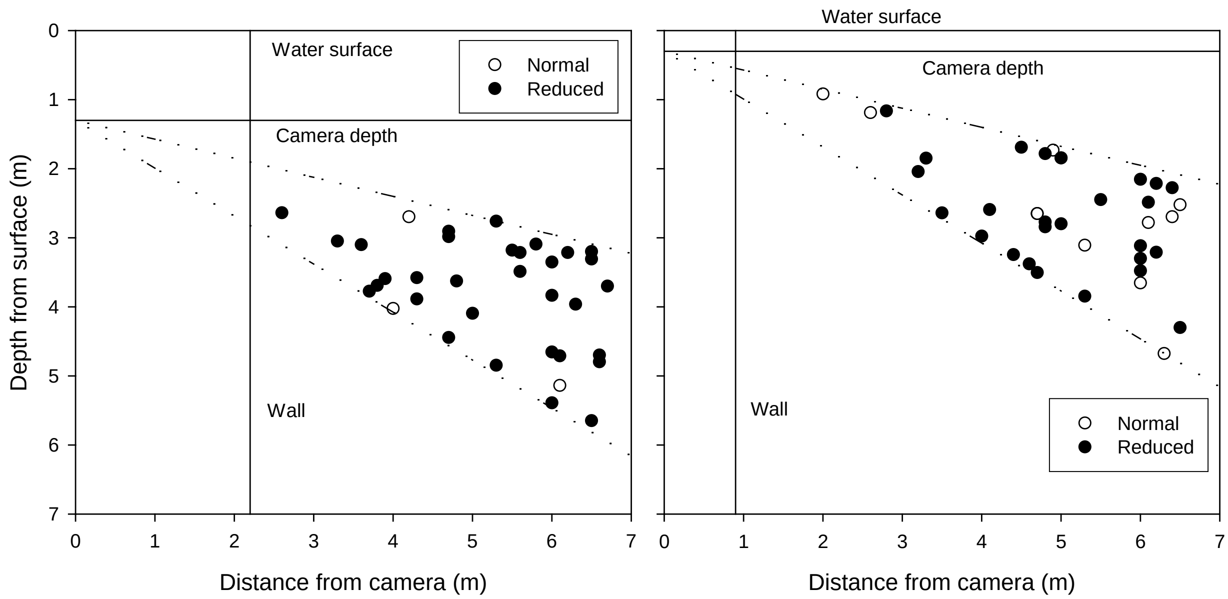

Figure 59. Locations where lamprey were first detected in the portrait mode deployment at SUE on 31 August-1 September (left panel) and 2 September (right panel). Dashed lines represent the DIDSON field of view. Solid lines represent the water surface inside the fishway entrance and approximate locations of the near and far fishway walls. Solid circles (●) show events scored during reduced fishway velocity operations and open circles (○) show events scored during normal operations. Note different camera depths.

Discussion

Monitoring adult Pacific lamprey migration behaviors at Columbia River basin dams is becoming more important to identify specific areas of difficult passage and behaviors that cannot be accomplished with traditional telemetry or acoustic monitoring (Johnson et al. 2011). To date, field assessments of lamprey migration behavior and passage success at lower Columbia River dams have relied primarily on data obtained from radiotelemetry (Moser et al. 2005; Clabough et al. 2010, Johnson et al. 2012) and HD-PIT detection (Keefer et al. 2009). While these methods provide strong quantifiable evidence of lamprey movements at larger scales, they have limited applicability for high-resolution spatial sampling of behavior or passage performance. Moreover, they do not provide information on lamprey distribution either horizontally (across the fishway) or vertically (depth) and many basic qualitative details of lamprey swimming behavior in and near fishways remain unknown. We found that DIDSON imagery can provide insight into lamprey behavior and help identify sites and structural configurations that improve lamprey attraction, passage, or collection at dams. DIDSON results from this pilot study can complement data collected using passive (i.e., PIT tags) and active (i.e., radio and acoustic transmitters) systems. Below we provide a summary of our methodological assessment, analyses of lamprey passage, and behavior (swimming direction, entrance and exit behavior, fish depth, and diel activity) with respect to our major study objectives and provide recommendations for future DIDSON deployments and data processing techniques.

Methodology Assessment

A basic goal of the study was to evaluate to what degree the DIDSON technology could be used to quantify adult lamprey behavior. This evaluation requires three elements: 1) can the technology resolve lamprey and confidently distinguish them from other species present?; if so, 2) what conditions are required to obtain adequate imagery?; and 3) can imagery be used to reliably and repeatedly quantify behavior or is it limited to qualitative assessments of behavior? A fourth issue relates to sample design and the inferential power of the results given the fixed sample volume of the DIDSON.

We were able to distinguish adult lamprey from other species using DIDSON technology. Adult lamprey have distinctive morphology and swimming behavior that allowed us to define specific identification criteria (Borazjani and Sotiropoulos 2009). In contrast, distinguishing among salmonid species is difficult or impossible because morphology and swimming behaviors differ only subtly among species. Swimming behavior was an important factor in identifying adult lamprey, particularly the anguiliform swimming motion and morphology. This motion was most discernible when the fish were imaged laterally (as in many landscape orientation images) and was less discernible when lampreys were effectively imaged from the anterior or posterior along the longitudinal axis of the fish (as in many portrait orientation images). The swimming form would also be less obvious when imaged dorsally. Duration of the image was also important during target identification and longer imagery sequences with multiple short frequency anguiliform waveforms moving through the body were diagnostic whereas shorter imagery clips with suggestive morphological characters but limited swimming duration were frequently scored with lower confidence. The combination of lamprey orientation to the camera and differences in the duration imaged probably contributed substantially to the observed variation in target confidence between portrait and landscape camera orientations and the observed differences among sites.

Distance from the DIDSON to the target fish is limited because the ability to distinguish between lamprey and other fishes was affected strongly by the resolution of the imagery collected. DIDSON cameras can collect imagery to 24 m (Johnson et al. 2010b), but image resolution declines with increasing sample window length (i.e., sample window lengths larger than 10 m requires use of the lower operational frequency which diminishes the resolution as a result of using fewer (48) beams than with the higher frequency (96 beams). The maximum distance imaged during this study was 14.5 m at Cascades Island. Across all sampling locations at Bonneville Dam we found that adult lamprey were easily discernible up to a range of 6-7 m. While it was possible to identify targets as lamprey at distances of 11-12 m, the confidence in target identification was lower and the ability of distinguish among species depended more strongly on the orientation of the fish to the camera. For instance, images at Cascades Island were collected at the longer ranges in an effort to image structures distant from the I-beam, but we concluded that review of these images was not cost-effective because reviewers could not identify them with confidence (evaluation of this site was lower in priority at the outset as well). We limited further data collection to a maximum sample window length of < 10 m and locations where useful data could be collected within this range.

Ideally each target could be identified with perfect confidence by independent observers during data review, though this is unlikely in practice. We used the among-viewer comparison to determine how repeatability and confidence differed, and how sampling error and potential biases introduced in the review process might affect the conclusions of the study.

The among-viewer assessment indicated that there can be significant challenges associated with adult lamprey identification using DIDSON. Agreement among viewers was quite good when lamprey were present in the field of view for several seconds, particularly in landscape deployments and when several of the identification criteria were present (i.e., anguilliform swimming, shape, size, or other characteristic behaviors). Agreement was low for short duration events (often < 1 sec) and those that did not clearly include multiple established criteria. Lamprey were also more difficult to confidently identify in portrait deployments or when many fish of multiple species were present simultaneously.

It may be possible to improve among-viewer agreement through additional training or more explicit definitions of criteria. However, we think that uncertainty will persist for many lamprey or lamprey-like targets identified using DIDSON given the relatively low resolution of the imagery compared to other technologies such as optical video and short event durations. As shown in Figures 6 and 7, our estimates of lamprey abundance (measured as events) and our estimates of among-viewer agreement were very sensitive to the confidence level assigned to each scored event. Because we attempted to score confidence using explicit criteria, we believe these patterns were caused by a combination of variation in detection probability (i.e., one reviewer observing and scoring short duration event while other simply did not observe it), variation in the interpretation of confidence level for individual events (i.e., whether to score a short duration event as lamprey, low confidence or score as unknown/salmonid), variation in the viewing speed (frames/sec) of imagery among viewers, and actual variation among events in the information content of the images. For instance, many low confidence events were scored by few reviewers, whereas high confidence events (longer, with more identifiable criteria by definition) were observed and scored by a majority or all reviewers (Figure 4). For these reasons, we recommend that future DIDSON lamprey studies include explicit use of criteria to identify lamprey and to assess confidence levels among viewers. These should include double-blind comparisons among viewers as well as sensitivity analyses to more realistically present metric estimates and their associated confidence intervals. Such assessments will be especially important to assess and minimize errors associated with reviewing during quantitative analyses, including enumeration, fishway entrance efficiency, or other passage metrics commonly used in tagged lamprey studies. Multiple-viewer effects should also be considered when assessing more general questions such as relative abundance across sites with similar deployments, lamprey interactions with other species, lamprey orientation direction, or distribution within the DIDSON field of view. Importantly, differences among reviewers in their willingness to score events as lamprey (even as low confidence events) and variation in detection probability among camera orientations have the potential to bias quantitative estimates of lamprey activity such as event rate or entrance efficiency. Low detection probability and shorter event durations will result in underestimates of lamprey activity and variation in willingness to score events can bias estimates high or low, particularly if conducted by single reviewer.

From our experience with automated event-scoring software for optical video data, we think it will be difficult to apply such software to DIDSON for lamprey in the short term. However, it may be possible to develop an adult lamprey training library for the AVEDac system (Eder, et al. 2011; Thompson et al. 2012) or similar software. If successful, such a system would greatly reduce the time and labor requirements currently needed to evaluate DIDSON data. Furthermore, an automated system would eliminate inter-observer biases (though other biases may be introduced). Perhaps the greatest immediate improvement would be use of algorithms that eliminated periods with no fish activity, which would be particularly useful in situations with low lamprey (and other fish) density where rare low frequency events may be easily missed during review.

The fishway environment affected the acoustic environment and image quality. For fish near the fishway floor or wall, the acoustic beams return from the fish and the bottom or fishway wall at approximately the same time resulting in superimposed images that made the fish appear transparent (simultaneous acoustic returns). The hard, smooth surface inside a fishway also produced an acoustic boundary and was an ideal environment to reflect sound that often produced bright echoes appearing as arcs or lines ("crosstalk") (Sound Metrics Corp. http://www.didson.com/SONAR101/ sn_sonar101.html). Periodically images with black radial lines appeared as a result of incorrect mapping of the display from objects beyond maximum range ("aliasing") (Sound Metrics Corp. http://www.didson.com/SONAR101/sn_sonar101.html). These phenomena were usually overcome by repositioning the camera (aspect angle) or adjusting the threshold during playback.

The spatial scale of DIDSON monitoring is limited to the sample volume and this greatly affects the ability to make inferences beyond the sample volume. In nearly all of our evaluations the camera was deployed in a single fixed orientation, and one that was predetermined by the location of available I-beams. Consequently, interpreting the observed behaviors or estimating quantitative metrics would require untenable assumptions. For instance, net entrance rate requires enumeration of up- and downstream movements through the entrance. If lamprey move downstream at different depths than upstream (or vice versa), estimates are likely to be strongly biased or even of the wrong sign (i.e., observed net downstream but true upstream movement). This limitation could be overcome for some study objectives using stratified sampling as in our pilot experiment in the junction pool. However, estimating metrics where high precision is desired (e.g., entrance efficiency, escapement) or that are comparable to those derived from radiotelemetry would require full coverage of the fishway using multiple DIDSONs simultaneously or a stratified sampling design followed by statistical evaluation of fish distribution. Stratified sampling is currently the least expensive method to assess vertical distributions of lamprey and more specific details about lamprey movements, including entrance efficiency estimation. This type of study design would require I-beams that run to the fishway floor to help standardize camera orientation across depths. We have installed such I-beams at the John Day North Fishway and will monitor behavior using a stratified vertical approach during the 2012 lamprey run.

Despite the limitations on inference imposed by the sampling design and range of the camera, the data collected in this study can be used to evaluate several aspects of lamprey behavior heretofore unknown, particularly within site. Additionally the data can be used to generate hypotheses about factors generating patterns observed within and among sites.

Biological Assessment

Event Rate – This pilot study demonstrated that DIDSON technology provided a temporal and spatial assessment of adult lamprey movement at a fishway within the available sample volume without altering their behavior. Adult lamprey had clearly discernible diel passage patterns. Lamprey activity was concentrated at night at all sample sites but was not confined to night-time hours. This type of nocturnal behavior has also been observed in radiotelemetry and PIT tag studies (Johnson et al. 2009b, Keefer et al. 2009, 2012) and in underwater video studies (Eder et al. 2011; Clabough et al. 2012).

We observed differences in lamprey movements among sites. However, we caution that some of the variability among sites was an artifact of non-random sampling (date effects) and differences in DIDSON deployment depth or the orientation of the camera relative to the fish (aspect angle). Some differences among sites in the DIDSON study paralleled those reported in radiotelemetry studies, such as the relatively high lamprey activity levels at SUE compared to other sites (Clabough et al. 2010). Lamprey behavior in relation to fishway water velocity at night was mixed when compared to radiotelemetry results (Johnson et al. 2012). For example, the DIDSON results suggested higher lamprey activity during normal velocity operations at SUE (landscape and portrait) and at both SDE and JP (landscape only), but higher activity during reduced velocity operations at NDE (landscape and portrait) and SDE (portrait only). The standby operation had the most activity at NUE (landscape) and was associated with the least activity at the other sites. Overall, the differences between the DIDSON and radiotelemetry results suggest the potential that the effects of the velocity treatment manifested upstream of the locations monitored by DIDSON. In addition to higher entrance efficiencies, guidance and attraction were consistently higher during reduced velocity conditions at all of the PH2 entrances when evaluated with radiotelemetry (Johnson et al. 2010a). Again, if movement behaviors differ with depth, comparisons between radiotelemtry and DIDSON metrics are invalid if DIDSON metrics are taken at a single depth. Incomplete vertical sampling, differences among sites, and the fact that DIDSON sampling provided no individual fish data could account for the inconsistencies observed. Fishway velocity test metrics were calculated for only unique individuals that approached and entered at the same site during the same treatment (Johnson et al. 2012). Although many of the trends we observed with this year's DIDSON study follow those from radiotelemetry studies, we caution that accurate assessment of fish movements would require full coverage of the fishway particularly if movements are location dependent.

Net Upstream Movement – In addition to enumeration, the DIDSON provided a method for quantifying swimming behavior. The DIDSON allowed us to characterize upstream and downstream movements and the orientation of lamprey as they passed through the acoustic beams. The highest percent of upstream movement was observed at the SUE and SDE entrances while PH2 north entrances (particularly NDE) were associated with relatively high percentages of fish moving downstream. These results are consistent with results from radiotelemetry studies which indicated higher entrance efficiencies at the PH2 south entrances compared to PH2 north entrances (Clabough et al. 2010; Johnson et al. 2012). Downstream movements were associated with lower confidence scoring at many sites. We think this may have been because lamprey were more likely to "drift" downstream (with head orientated upstream) and were more difficult to classify because they didn't portray the classic anguilliform swimming motion. Fish moving downstream also passed more rapidly through the FOV giving the reviewers less time (often < 1 sec) to identify the target.

Lateral distribution – Somewhat unexpectedly, we observed lamprey swimming throughout the monitored water column, with no apparent preference for routes adjacent to walls. Similarly, lamprey were vertically distributed throughout the sampled volumes, often at relatively shallow depths (~1.5 – 4 m; Figure 57) Lamprey orientation to walls and especially to the fishway floor was observed in the artificial fishway experiments (Keefer et al. 2010, 2011) and we expected similar behaviors in the fishway entrance sites monitored with the DIDSON. Three factors may have affected this result. First, we did not monitor the lower sections of the fishway entrances (where most lamprey activity was expected) because of the I-beam limitations and event rates may have been higher at deeper depths. Second, the triangular shape of the FOV resulted in minimal sampling of the near wall in all deployments, and activity in this portion of the fishway may have been underestimated. Third, the mid-elevation deployments may have been biased towards downstream-moving lamprey, which we suspect may be more likely to use the higher velocity in the middle of the fishway channels. In spite of these caveats, many lamprey were observed moving upstream in the middle of the fishway entrance channels, and this suggests that they may be less substrate-oriented and more rheotactically-oriented in these locations than previously thought. It is also possible that lamprey were more able to swim freely in mid-channel locations given the reduced fishway velocities that occurred at night.

Future DIDSON deployments closer to the fishway floor will help establish whether lampreys do preferentially orient to substrate and walls. Such information will be important for the siting of lamprey collection and passage structures (LPS) like the structure that will be installed at NDE in 2012-2013. Similarly, future deployments at Cascades Island and John Day Dam fishway should demonstrate whether velocity-reducing features like bottom-mounted bollards provide routes that are preferentially used by lamprey. Stratified vertical sampling with DIDSON within the full water column will also provide a more complete understanding of how lamprey are distributed within the entrance areas and whether those distributions change in response to light level, velocity operations, predators or other factors.

Portrait Depth Data – In this pilot study, portrait-mode deployments were concentrated towards the end of the migration (see Figure 3). For this reason, we expected to observe fewer lamprey events in the portrait mode than in the landscape mode, on average. In fact, we observed two-to-three times fewer lamprey with the DIDSON in portrait orientation and lamprey were generally scored with lower confidence. The reason portrait mode may have been less efficient for lamprey detection had to do with the shape of the displayed image making target identification much more difficult. Additionally, lamprey were in the FOV for shorter periods, on average, in the portrait mode. However, the combination of the two deployments provided complimentary information on upstream-downstream movements, depth, and range. We recommend use of landscape orientation with the lamprey moving perpendicularly across the field whenever possible to maximize target detection probability and the confidence of identifications. We also recommend the use of stratified sampling in landscape orientation as preferable to portrait mode for characterizing depth distributions.

Our primary aim in using the portrait orientation was to estimate lamprey depth when in the FOV. In situ swimming depths within our sample volumes did not indicate a strong depth preference within the FOV during the day or night. However, as mentioned previously the I-beam depth precluded sampling the bottom strata near the fishway floor and again, we caution that the distribution within the FOV may not be representative across the fishway entrance. Adult lamprey are known to be cryptic and often use habitats near the bottom, hiding under boulders or other structures (Moser et al. 2007b). Migrating adult lamprey may also concentrate near the bottom during migration and may be structure-oriented inside fishways, but limitations of our sampling gear prohibited a direct evaluation in 2011. Additional research is needed to more fully describe the spatial distribution of adult lamprey near and inside fishway entrances. Notably, the vertical distribution of lamprey was counter to these hypotheses within the JP, though the presence of high sturgeon densities in this location may have altered lamprey distribution.

The fishway floor was observed in landscape mode in the JP. At this site, we saw no evidence that lamprey behaviorally responded to diffuser gratings. Instead, most lamprey appeared to swim well above diffusers. Low water velocity in the observed section of the JP likely eliminated any need for lamprey to attach to the floor.

Prevalence of Attachments – Unexpectedly, we observed very few lamprey with their oral discs attached to substrate or walls given the exposure to high water velocities at fishway entrances. Lamprey movement in areas with high water velocities has been described as "intermittent locomotion" where movement is interspersed with frequent attachments (Kent et al. 2009; Keefer et al. 2010). However, this behavior may differ in areas with predators, or perhaps water velocities were slow enough that fish did not need to attach (this was most likely a factor during reduced velocity operations). Attachment estimates are also conservative because attached fish were near the outer range of the camera (typically the far wall) and were often difficult to see, and the near wall and floor were not monitored. Furthermore, the target strength of an attached lamprey was often times weaker and simultaneous acoustic returns often degraded lamprey images near walls.

Sturgeon Interactions – Our DIDSON results provide the first observations of lamprey in the presence of white sturgeon under field conditions. Sturgeon presence was generally associated with lower lamprey activity. Downstream movements by lamprey were also more common when sturgeon were present, consistent with the hypothesis that lampreys retreated downstream when detecting a potential predator upstream. Lamprey event rates were higher when sturgeon were absent at SUE (portrait only), SDE (both deployments), NDE (portrait only), NUE (only landscape data collected), and in the JP. We also identified a likely sturgeon effect in the tilting DIDSON experiment in the JP, where higher lamprey event rates were recorded higher in the water column where there were fewer sturgeon.

We think it is likely that adult lamprey modified their behavior in response to white sturgeon presence. The mechanisms of this response are currently unknown, but may involve chemoreception (i.e., lamprey response to sturgeon odors or to lamprey alarm cues) or other detection systems (i.e., visual cues). This result, in conjunction with observations at the margin of the diffuser grating suggest that predators or hydraulic effects upstream (e.g., in the transition pool) may be responsible for lamprey turnarounds in the PH2 Junction Pool area, rather than the immediate effects of water upwelling through diffusers that adults first encounter within the monitored FOV.

Development of Passage Metrics

Comparability of DIDSON-based metrics to active telemetry metrics (i.e., radiotelemetry), including entrance and exit rates and passage metrics (entrance efficiency), was challenging. We calculated lamprey event rates and upstream and downstream movements and found behaviors and entrance ratios similar to those derived from radiotelemetry at some locations, but not others. As suggested previously, we think it is likely that lamprey behavior and abundance varies with depth, as observed in the Junction Pool. For example, lamprey may be more likely to enter fishways near the fishway floor, but be more likely to exit back to the tailrace from higher in the water column where water velocity tends to be higher and predator density may be lower. Spatial variation of this type has the potential to substantially bias DIDSON-based estimates of lamprey entrance efficiency and may explain some the differences among sites and between the DIDSON and previous radiotelemetry results described above.

DIDSON sampling also provides no individual fish data or fate information. For this reason, it is not possible to calculate metrics such as fishway entrance events/fish or to link any observed event or behavior with subsequent behaviors such as dam passage. In other words, only local-scale events and metrics that do not require individual fish information can be estimated using DIDSON. Future studies that combine active telemetry (i.e., radio or acoustic) with DIDSON may help calibrate some DIDSON-based passage or efficiency metrics. Regardless, DIDSON should currently be considered a complimentary behavioral assessment method rather than a replacement method for tagging studies.

Conclusions

Overall, future use of the DIDSON technology should consider trade-offs between study objectives, costs and the relative strengths and weaknesses of other technologies. For some applications, DIDSON appears to be superior to underwater optical video, which has been used to evaluate lamprey behavior but is constrained to very specific locales and conditions and has a smaller maximum range under many underwater conditions (Keefer et al. 2010; Eder et al. 2011; Clabough et al. 2012; Thompson et al. in review). The DIDSON is a relatively new tool for adult Pacific lamprey research and we found that it fills a niche for passive monitoring at fine-to-moderate spatial scales.

Although there are many advantages of using the DIDISON as a tool for adult Pacific lamprey research, there are constraints and disadvantages. Appropriate selection of deployment sites is critical both because there are range limitations for confident lamprey identification and because some environments are acoustically or structurally challenging to monitor. Underwater acoustic (and optical) cameras also require specific structures (I-beams, special trolleys, and access to power) that must be in place prior to deploying the camera and collecting data. Post collection, data interpretation can be time and labor intensive and therefore expensive. In this pilot study, we found that the I-beams used to deploy the DIDSONs did not span the water column and restricted our ability to sample the lower portion of the water column where lamprey are likely to congregate (Moser et al. 2007b; Keefer et al. 2010) or were too far from the area of interest (particularly at the Cascades Island site). Should lamprey abundance continue to decline, passive monitoring techniques like DIDSON are needed to minimize lamprey capture, handling, and tagging, all of which can result in negative delayed effects and mortality (Jepsen et al. 2002; Mesa et al. 2003; Moser et al. 2007a). Use of optical video is most appropriate for questions at small scales (movement through weir orifices, etc.) and telemetry is most useful when population-scale inferences are desired at larger spatial scales. DIDSON will likely be most useful for situations evaluating qualitative behavioral responses to structures or other conditions where video is inappropriate because of spatial scale or optical conditions, and situations where lamprey abundance prevents collection and tagging.

These results demonstrate the feasibility of using DIDSON to assess the movements and behavior of adult Pacific lamprey in confined environments. More specifically these data provide qualitative information on the lateral and vertical position of fish in the sample volume and reflect behavioral responses to environmental and operational conditions learned from telemetry studies. Furthermore, these results indicate that we can infer swimming direction and heading, enumerate attachment events, and quantify behavioral responses to predatory fish. The DIDSON is an effective monitoring tool for specific tasks (such as monitoring behavior at a specific fishway location); however, the ability to extend the technology to calculate passage metrics is limited because of the range and sample volume limit the spatial inference of the technology. Nonetheless, DIDSON evaluations can provide important and results that complement PIT tag and radiotelemetry studies.

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Appendix A

Appendix Table 1. DIDSON camera deployment parameters at the south downstream entrance (SDE) in 2011.

Location	*Date*	*Camera*	*Orientation*	*Tilt*	*Aux. lens*	*Camera depth (m)*	*Avg. Gate Depth (m)*	*Height above Gate (m)*	*Tailrace elevation (m)*	*Camera start (m)*	*Camera range (m)*
SDE											
	15-Jul	new	landscape	-8	yes	3.8	3.9	0.1	7.8	0.4	5.4
	16-Jul	new	landscape	-7	yes	3.8	3.9	0.1	7.1	0.8	5.8
	17-Jul	new	landscape	-8	yes	3.8	3.9	0.1	6.9	0.8	5.8
	18-Jul	new	landscape	-8	yes	3.8	3.9	0.1	7.0	0.8	5.8
	19-Jul	new	landscape	-8	yes	3.8	3.9	0.1	7.0	0.8	5.8
	20-Jul	new	landscape	-8	yes	3.8	3.9	0.1	6.9	0.8	5.8
	25-Jul	old	landscape	-8	no	3.4	3.9	0.5	6.2	1.1	5.6
	26-Jul	old	landscape	-8	no	3.4	3.9	0.5	6.1	1.1	5.6
	27-Jul	old	landscape	-8	no	3.4	3.9	0.5	6.0	1.1	5.6
	28-Jul	new	landscape	-8	no	3	3.9	0.9	6.0	1.1	5.6
	9-Aug	new	portrait	60	no	1.5-2.1	3.9	1.9 - 2.5	5.2	0.4	5.4
	10-Aug	new	portrait	59	no	1.5-2.1	3.9	1.9 - 2.5	5.1	0.4	5.4
	11-Aug	new	portrait	59	no	1.5-2.1	3.9	1.9 - 2.5	5.2	0.4	5.4
	31-Aug	new	portrait	-31	no	1.7-1.8	3.9	2.2 - 2.3	4.5	0.8	5.8
	1-Sep	new	portrait	-31	no	1.7-1.8	3.9	2.2 - 2.3	4.4	0.8	5.8
	2-Sep	new	portrait	-31	no	0.2-1.8	3.9	2.3 - 3.8	3.4	0.8	5.8

Appendix Table 2. DIDSON camera deployment parameters at the south upstream entrance (SUE) in 2011.

Location	*Date*	*Camera*	*Orientation*	*Tilt*	*Aux. lens*	*Camera depth (m)*	*Avg. Gate Depth (m)*	*Height above Gate (m)*	*Tailrace elevation (m)*	*Camera start (m)*	*Camera range (m)*
SUE											
	28-Jul	old	landscape	-8	yes	3.0	3.8	0.8	6.0	2.3	6.8
	29-Jul	old	landscape	-8	yes	3.0	3.8	0.8	5.6	2.3	6.8
	30-Jul	old	landscape	-8	yes	3.0	3.8	0.8	5.7	2.3	6.8
	31-Jul	old	landscape	-8	yes	3.0	3.8	0.8	5.5	2.3	6.8
	1-Aug	old	landscape	-8	yes	3.0	3.8	0.8	5.9	2.3	6.8
	2-Aug	old	landscape	-8	yes	3.0	3.8	0.8	5.8	2.3	6.8
	3-Aug	old	landscape	-8	yes	3.0	3.8	0.8	5.2	2.3	6.8
	11-Aug	new	portrait	-7	yes	1.8	3.8	2.0	5.2	1.7	6.7
	12-Aug	new	portrait	-7	yes	1.8	3.8	2.0	5.5	1.7	6.7
	13-Aug	new	portrait	-7	yes	1.8	3.8	2.0	5.1	1.7	6.7
	14-Aug	new	portrait	-7	yes	1.8	3.8	2.0	4.5	1.7	6.7
	15-Aug	new	portrait	-8	yes	1.8	3.8	2.0	4.9	1.7	6.7
	16-Aug	new	portrait	-7	yes	1.8	3.8	2.0	5.2	1.7	6.7
	17-Aug	new	portrait	-7	yes	1.8	3.8	2.0	5.3	1.7	6.7
	31-Aug	old	portrait	-30	no	1.4	3.8	2.4	4.5	2.3	6.8
	1-Sep	old	portrait	-30	no	1.3	3.8	2.5	4.4	2.3	6.8
	2-Sep	old	portrait	-30	no	0.3	3.8	3.5	3.4	2.3	6.8

Appendix Table 3. DIDSON camera deployment parameters at the north downstream entrance (NDE) in 2011.

Location	*Date*	*Camera*	*Orientation*	*Tilt*	*Aux. lens*	*Camera depth (m)*	*Avg. Gate Depth (m)*	*Height above Gate (m)*	*Tailrace elevation (m)*	*Camera start (m)*	*Camera range (m)*
NDE											
	6-Jul	new	landscape	-8	yes	1.8	3.9	2.1	8.4	1.3	6.3
	7-Jul	new	landscape	-8	yes	2.0	3.9	1.9	8.6	1.3	6.3
	8-Jul	new	landscape	-8	yes	2.2	3.9	1.7	8.6	1.3	6.3
	9-Jul	new	landscape	-8	yes	2.0	3.9	1.9	8.5	1.3	6.3
	10-Jul	new	landscape	-8	yes	1.9	3.9	2.1	8.3	1.3	6.3
	11-Jul	new	landscape	-8	yes	1.7	3.9	2.2	8.1	1.3	6.3
	12-Jul	new	landscape	-8	yes	1.6	3.9	2.3	7.6	1.3	6.3
	13-Jul	new	landscape	-8	yes	1.8	3.9	2.1	7.3	1.3	6.3
	14-Jul	new	landscape	-8	yes	1.8	3.9	2.1	7.4	1.3	6.3
	14-Jul	new	landscape	-38	yes	1.8	3.9	2.1	7.4	1.3	6.3
	15-Jul	new	landscape	-38	yes	1.8	3.9	2.1	7.8	1.3	6.3
	6-Aug	old	portrait	-10	no	2.6	3.9	1.3	5.3	1.5	6.0
	7-Aug	old	portrait	-10	no	2.6	3.9	1.3	4.8	1.5	6.0
	9-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	5.2	1.5	6.0
	10-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	5.1	1.5	6.0
	11-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	5.2	1.5	6.0
	12-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	5.5	1.5	6.0
	13-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	5.1	1.5	6.0
	14-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	4.5	1.5	6.0
	15-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	4.9	1.5	6.0
	16-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	5.2	1.5	6.0
	17-Aug	old	portrait	-10	no	1.5-2.1	3.9	1.8-2.4	5.3	1.5	6.0

Appendix Table 4. DIDSON camera deployment parameters at the north upstream entrance (NUE) in 2011.

Location	*Date*	*Camera*	*Orientation*	*Tilt*	*Aux. lens*	*Camera depth (m)*	*Avg. Gate Depth (m)*	*Height above Gate (m)*	*Tailrace elevation (m)*	*Camera start (m)*	*Camera range (m)*
NUE											
	9-Jun	old	landscape	var	no	var	2.9	var	10.1	1.5	6.0
	10-Jun	old	landscape	var	no	var	2.9	var	10.1	1.5	10.4
	17-Jun	old	landscape	-45	yes	2.4	2.9	0.5	10.1	0.8	5.2
	18-Jun	old	landscape	-45	yes	2.4	2.9	0.5	9.9	0.8	5.2 to 0810
	18-Jun	old	landscape	-45	yes	3.7	2.9	-0.8	9.9	0.8	9.7 after 2100
	19-Jun	old	landscape	-45	yes	3.7	2.9	-0.8	9.6	0.8	9.7

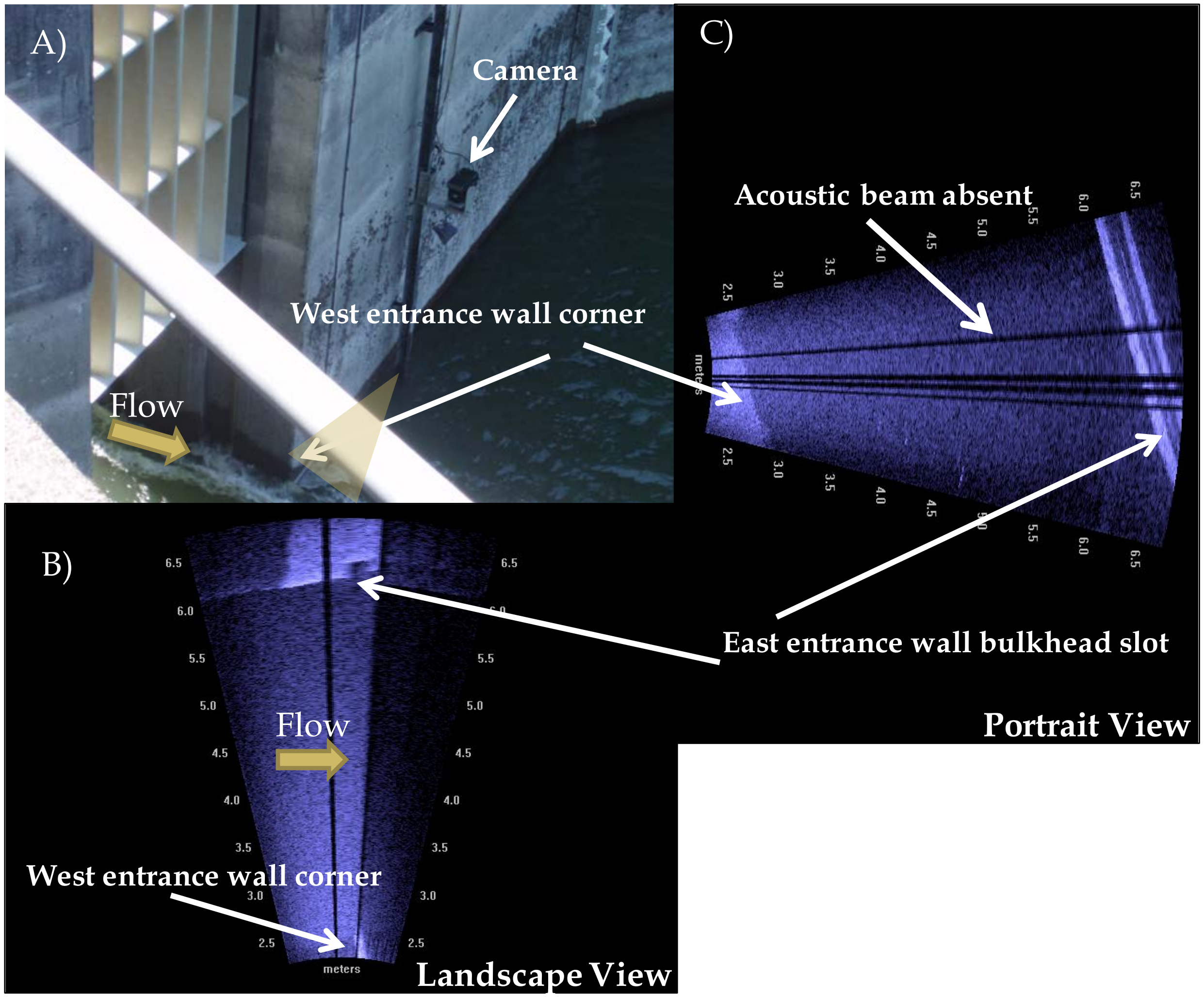
Appendix Table 5. DIDSON camera deployment parameters at the junction pool (JP) in 2011.

Location	*Date*	*Camera*	*Orientation*	*Tilt*	*Aux. lens*	*Camera depth (m)*	*Tailrace elevation (m)*	*Camera start (m)*	*Camera range (m)*
JP									
	28-Jul	new	landscape	-10	no	5.8	6.0	0.8	5.8
	29-Jul	new	landscape	-9	no	5.8	5.6	1.7	6.7
	30-Jul	new	landscape	-8	no	5.8	5.7	1.7	6.7
	31-Jul	new	landscape	-8	no	5.8	5.5	1.7	6.7
	1-Aug	new	landscape	-8	no	5.8	5.9	1.7	6.7
	5-Aug	new	landscape	-28, 0, 28	yes	4.1	5.3	1.7	6.7
	6-Aug	new	landscape	-28, 0, 28	yes	4.1	4.8	1.7	6.7
	18-Aug	new/old	landscape/portrait	-1, 0	no	5.3	5.3	1.7	11.7
	19-Aug	new/old	landscape/portrait	-1, 0	no	5.3	5.4	1.7	11.7
	20-Aug	new/old	landscape/portrait	-1, 0	no	5.3	4.7	1.7	11.7
	21-Aug	new/old	landscape/portrait	-1, 0	no	5.3	4.6	1.7	11.7

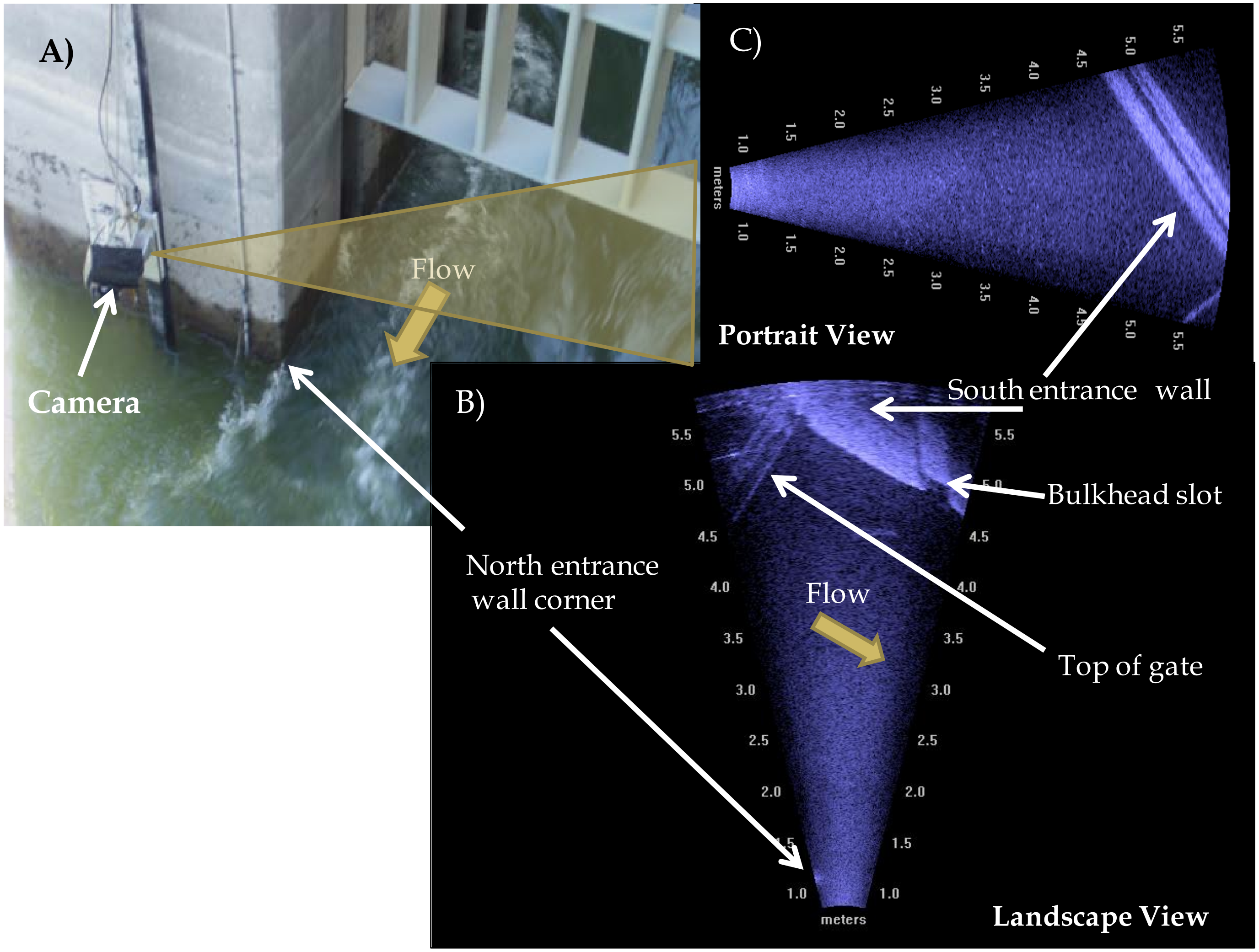
Appendix Table 6. DIDSON camera deployment parameters at the Cascades Island entrance (CI) in 2011.

Location	*Date*	*Camera*	*Orientation*	*Tilt*	*Aux. lens*	*Camera depth (m)*	*Tailrace elevation (m)*	*Camera start (m)*	*Camera range (m)*
CI									
	21-Jun	old	landscape	-10	yes	-	9.2	5.6	14.5
	22-Jun	old	landscape	-10	yes	-	9.3	5.6	14.5
	23-Jun	old	landscape	-10	yes	-	9.3	5.6	14.5
	29-Jun	old	landscape	-10	yes	-	8.7	6.7	11.2
	30-Jun	old	landscape	-10	yes	-	8.6	6.7	11.2
	2-Jul	old	landscape	-10	yes	3.8	9.2	6.7	11.2
	3-Jul	old	landscape	-10	yes	3.8	9.1	6.7	11.2
	22-Jul	new	landscape	-10	no	3.0	6.7	7.9	12.9
	23-Jul	new	landscape	-9	no	2.7	6.4	7.9	12.9
	24-Jul	new	landscape	-10	no	2.7	6.4	7.9	12.9
	25-Jul	new	landscape	-8	no	2.4	6.2	7.9	12.9
	25-Jul	new	landscape	-8	no	2.4	6.2	5.4	10.4
	26-Jul	new	landscape	-7	yes	2.3	6.1	5.4	10.4
	27-Jul	new	landscape	-7	yes	2.2	6.0	5.4	10.4
	28-Jul	new	landscape	-7	yes	2.1	6.0	5.4	10.4

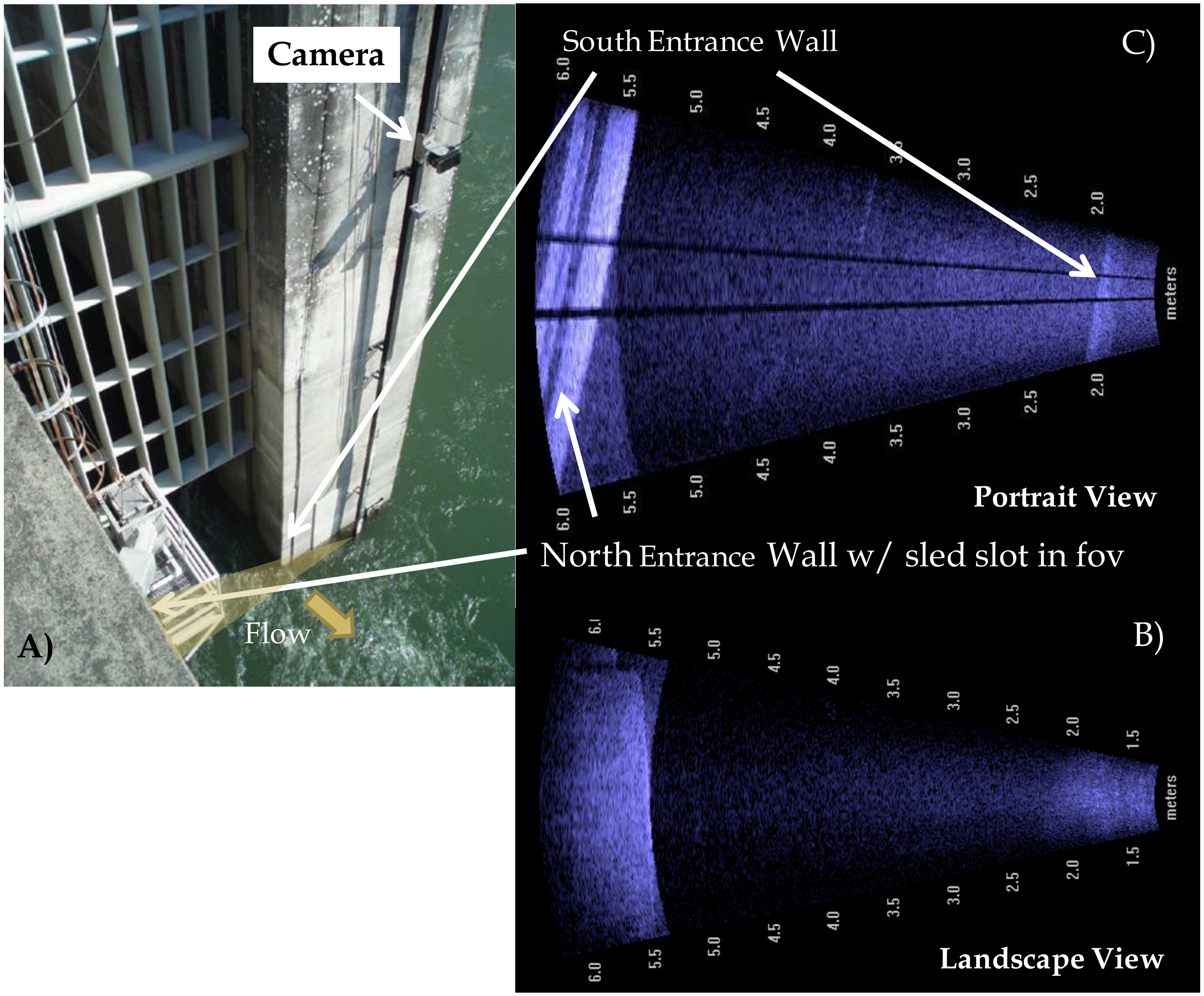
Appendix B



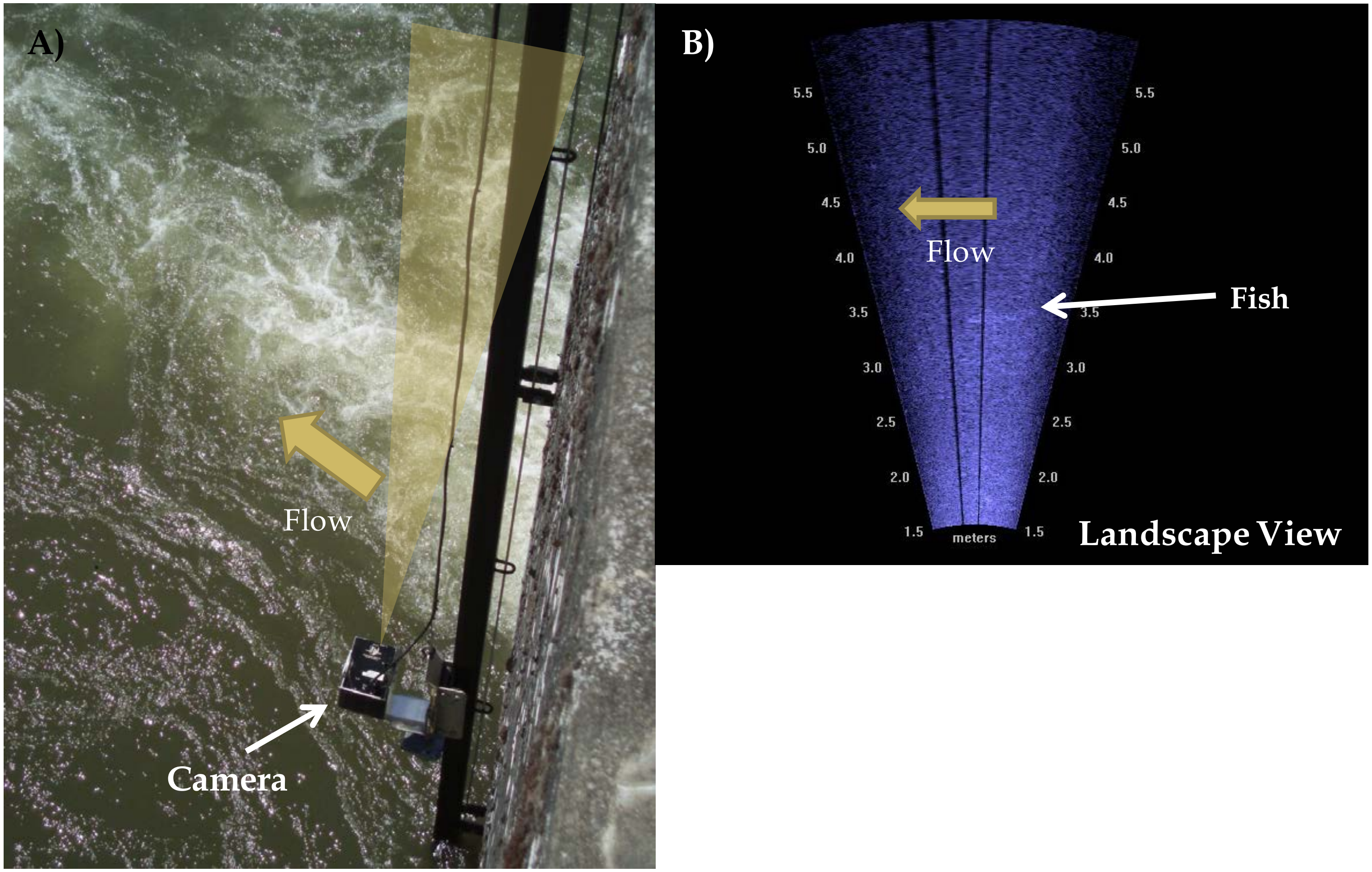
Appendix B Figure 1. A) DIDSON camera beam location at the south upstream entrance (SUE), B) SUE landscape view, and C) SUE portrait view.



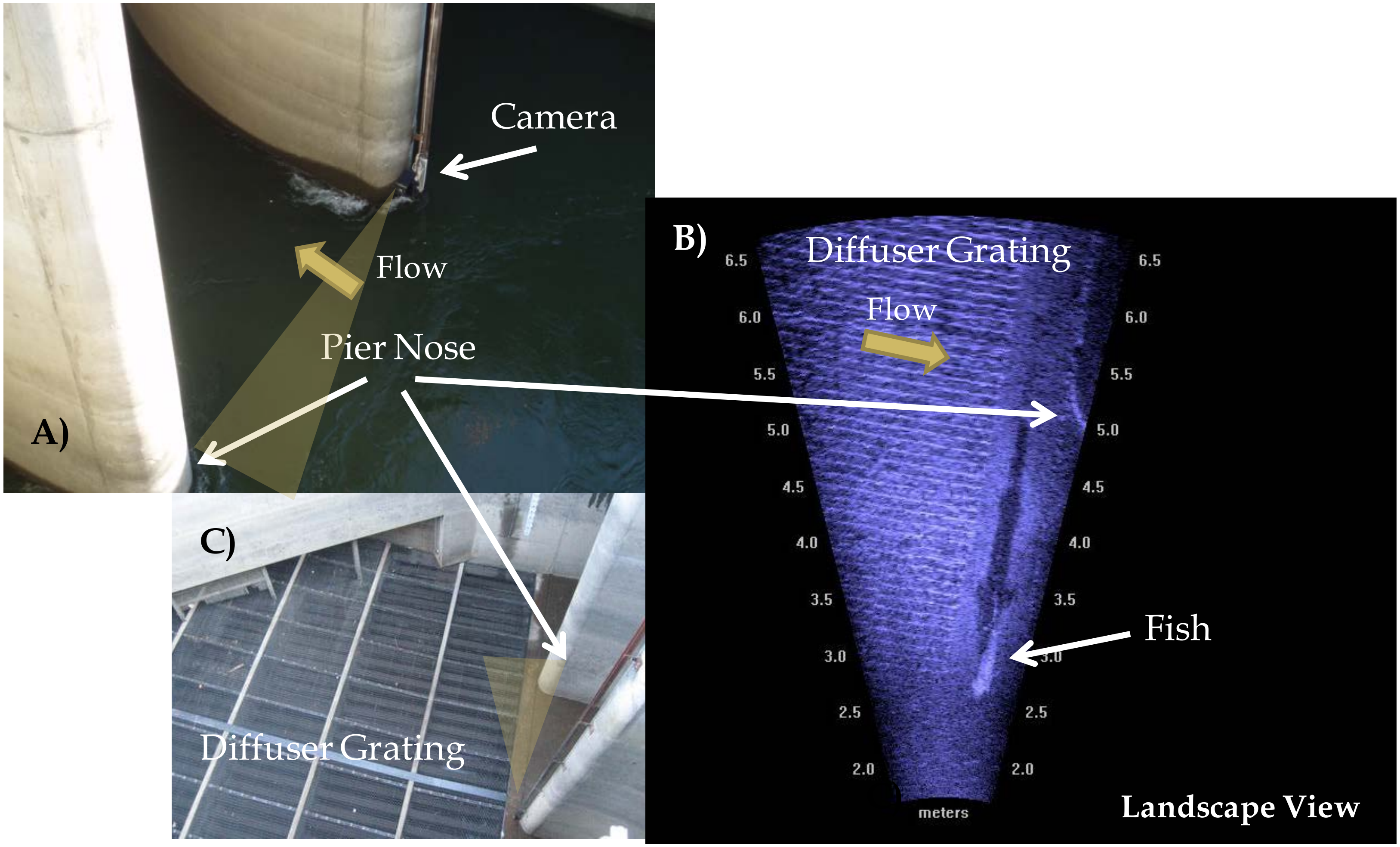
Appendix B Figure 2. A) DIDSON camera beam location at the south downstream entrance (SDE), B) SDE landscape view, and C) SDE portrait view.



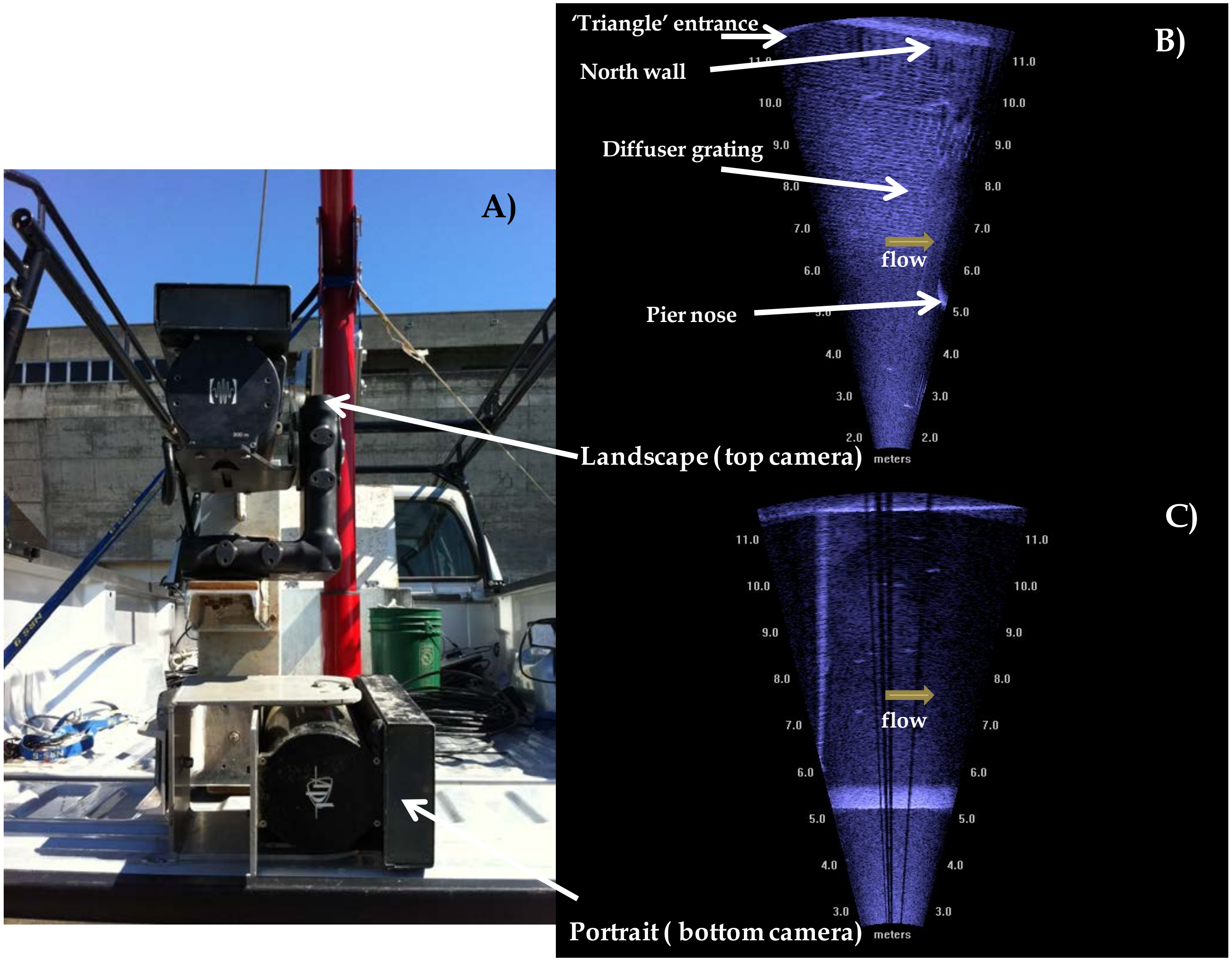
Appendix B Figure 3. A) DIDSON camera beam location at the north downstream entrance (NDE), B) NDE landscape view, and C) NDE portrait view.



Appendix B Figure 4. A) DIDSON camera beam location at the north upstream entrance (NUE) and B) NUE landscape view.



Appendix B Figure 5. A) DIDSON camera beam location at the junction pool (JP), B) JP landscape view, and C) JP diffuser grating image.



Appendix B Figure 6. A) DIDSON camera beam location at the junction pool (JP) with stacked camera deployment, B) JP landscape view, and C) JP portrait view.